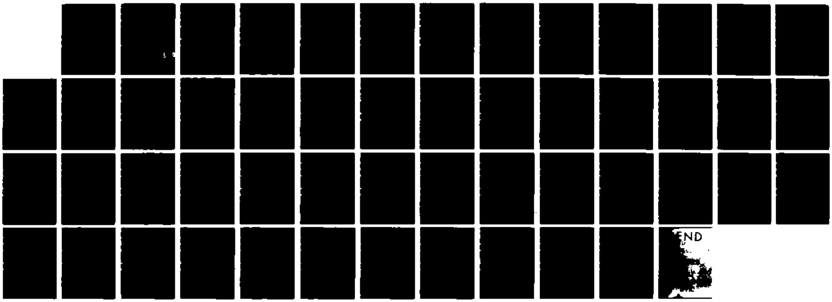
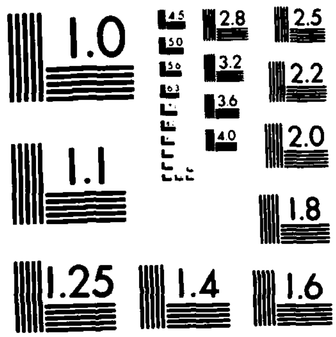
AD-A146 839 RED RIVER OF THE NORTH MODELING EVALUATION REPORT TO INTERNATIONAL SOURIS-RED RIVERS ENGINEERING BOARD(U) RED RIVER MODELING TASK FORCE ST PAUL MN 1/1

UNCLASSIFIED R D HOFER ET AL. SEP 81 F/G 8/8 NL

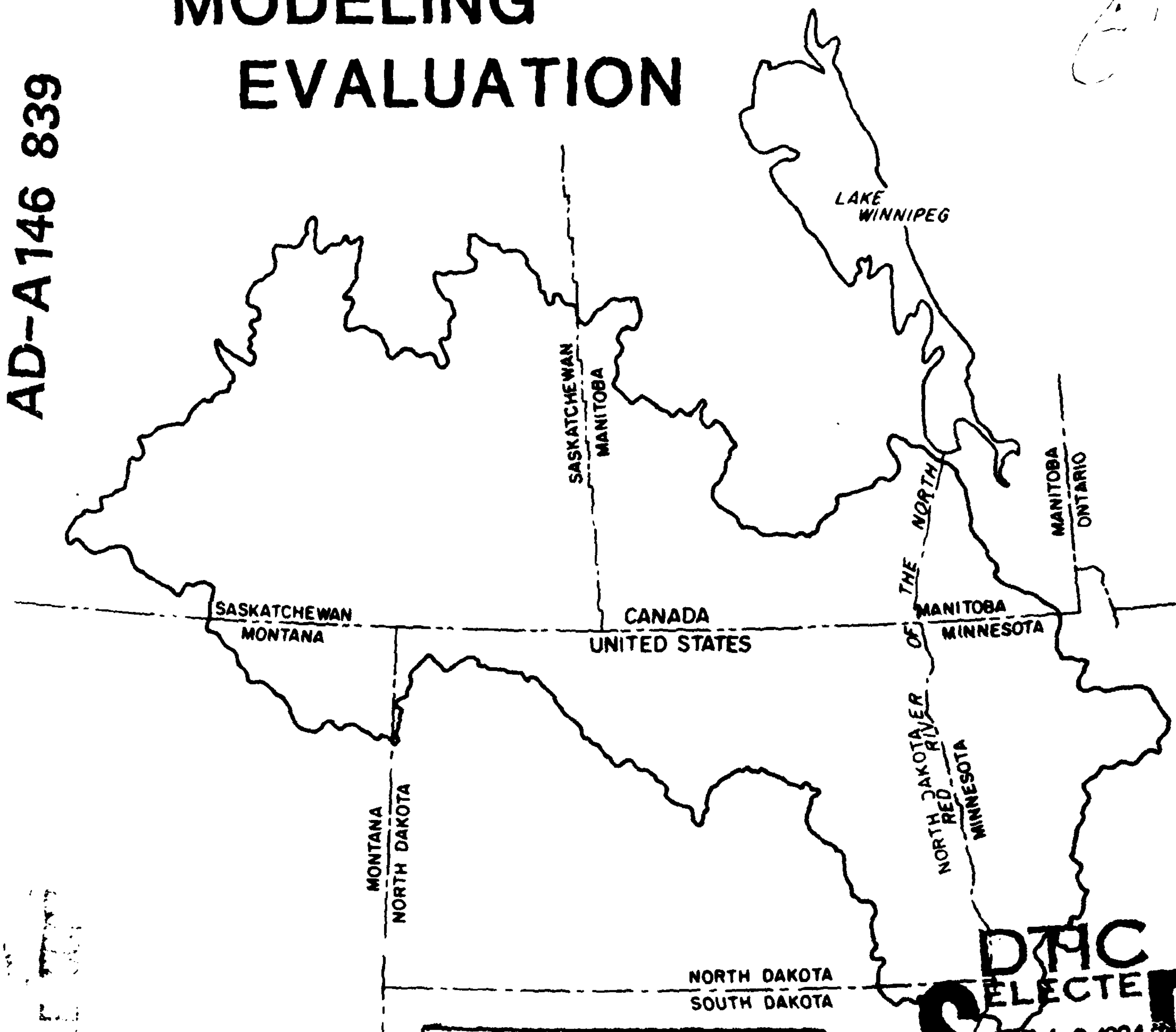




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

RED RIVER OF THE NORTH MODELING EVALUATION

AD-A146 839



This document has been approved for public release and sale; its distribution is unlimited.

DTIC
ELECTE
OCT 1 9 1984
S D
A

REPORT TO
INTERNATIONAL SOURIS-RED RIVERS ENGINEERING BOARD
BY
RED RIVER MODELING TASK FORCE

SEPTEMBER 1981

84 10 16 143

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) RED RIVER OF THE NORTH MODELING EVALUATION; Report of the Red River Modeling Task Force.	5. TYPE OF REPORT & PERIOD COVERED October 1980-September 1981
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R.D. Hofer, L.E. Kowalski, F.R.J. Martin, D.A. Sprynczynatyk, L.D. Seymour, R.J. Bowering	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Red River Modeling Task Force	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS International Souris-Red Rivers Engineering Board	12. REPORT DATE September 1981
	13. NUMBER OF PAGES 42 p.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) U.S. Army Engineer District, St. Paul 1135 USPO & Custom House St. Paul, Minnesota 55101	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

CANADA
HYDRAULIC MODELS
FLOODING
RED RIVER OF THE NORTH
INTERNATIONAL RELATIONS
UNITED STATES

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Red River Modeling Task Force was established to review the four computer models being considered by the U.S. Army Corps of Engineers for modeling the Red River Basin in the United States. These models include: the water surface profile model (HEC-2), the low-flow model (HEC-3), the high-flow model (HEC-5), and the expected annual damages model (EAD). In addition the task force was instructed to prepare a report on the capabilities of these models for providing data and technical information related to the impact of existing and

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

proposed river or ring dikes, impact of existing and proposed works such as reservoir and dike modifications on flow condition, impact of agricultural drainage and possibility of an expansion model being developed for the entire Red River basin.

The Red River Modeling Task Force was appointed by the Board from Federal, State and Provincial agencies that had the technical expertise required to carry out all aspects of the study.

INTERNATIONAL SOURIS-RED RIVERS ENGINEERING BOARD

REPORT OF RED RIVER MODELING TASK FORCE

Accession For
NTIS GRA&I
DTIC TAB
Unannounced
Justification
By
Distribution/
Availability Codes
Avail and/or
Dist Special
A

SEPTEMBER 1981

INTERNATIONAL SOURIS-RED RIVERS ENGINEERING BOARD

RED RIVER MODELING TASK FORCE

29 September 1981

International Souris-Red Rivers Engineering Board
Washington, D.C., United States
Regina, Saskatchewan, Canada

Gentlemen:

The Red River Modeling Task Force, established by the International Souris-Red Rivers Engineering Board on November 20, 1980 has completed the studies required to respond to the Terms of Reference adopted by the Board on October 8, 1980. The results of the studies are included in the attached report and appendix.

The Task Force is prepared to respond to any questions the Board may have concerning this assignment and the report, and the Task Force awaits your further direction in this regard.

Yours sincerely,

L. E. Kowalski

L. E. KOWALSKI
United States Co-chairman

R. D. Hofer

R. D. HOFER
Canadian Co-chairman

David A. Sprynczynatyk

D. A. SPRYNCZYNATYK

Fred R. J. Martin

F. R. J. MARTIN

L. D. SEYMOUR

R. J. BOWERING

TABLE OF CONTENTS

ITEM			PAGE
LETTER OF TRANSMITTAL			
APPENDIX.			ii
TABLES.			iii
FIGURES			iv
I	INTRODUCTION AND STUDY APPROACH		1
II	MODELS.		3
	A.	HEC-2 MODEL	3
		1. MODEL DESCRIPTION.	3
		2. MODEL APPLICATION.	3
		3. MODEL COST	10
		4. MODEL EXTENSION AND ADAPTABILITY	10
		5. MODEL ASSESSMENT	12
		6. MODEL ALTERNATIVES	12
	B.	HEC-3 MODEL	12
		1. MODEL DESCRIPTION.	12
		2. MODEL APPLICATION.	14
		3. MODEL COST	14
		4. MODEL EXTENSION AND ADAPTABILITY	16
		5. MODEL ASSESSMENT	16
		6. MODEL ALTERNATIVES	16
	C.	HEC-5 MODEL	18
		1. MODEL DESCRIPTION.	18
		2. MODEL APPLICATION.	19
		3. MODEL COST	19
		4. MODEL EXTENSION AND ADAPTABILITY	19
		5. MODEL ASSESSMENT	21
		6. MODEL ALTERNATIVES	21

TABLE OF CONTENTS (CONT)

ITEM		PAGE
	D. EXPECTED ANNUAL DAMAGE PROGRAM	22
	1. MODEL DESCRIPTION	22
	2. MODEL APPLICATION	24
	3. MODEL COST	24
	4. MODEL EXTENSION AND ADAPTABILITY	24
	5. MODEL ASSESSMENT	26
	6. MODEL ALTERNATIVES	26
III	OTHER STUDIES	27
	A. CH_2M HILL REPORT - ANALYSIS OF EXISTING HYDROLOGIC MODELS, RED RIVER OF THE NORTH DRAINAGE BASIN, NORTH DAKOTA AND MINNESOTA	27
	B. UNITED STATES GEOLOGICAL SURVEY - STUDY OF CHANGES IN HYDROLOGIC RESPONSE OF THE RED RIVER OF THE NORTH	28
	C. MANITOBA FLOOD FORECASTING STUDY	29
IV	MODELING RESULTS	30
	A. HEC-2 MODEL	30
	B. HEC-5 MODEL	32
	C. DISCUSSION	36
V	CONCLUSIONS	38
APPENDIX		
	TERMS OF REFERENCE	
	PLAN OF STUDY	

TABLES

TABLE PAGE

1 SUMMARY OF HEC-2 MODELING RUNS, RED RIVER OF THE NORTH, GRAND FORKS TO EMERSON 31

2 SUMMARY OF HEC-5 MODELING RUNS, RED RIVER OF THE NORTH, GRAND FORKS TO EMERSON 33

3 SENSITIVITY ANALYSIS FOR HEC-5 MODEL, RED RIVER OF THE NORTH, GRAND FORKS TO EMERSON. 34

4 IMPACT OF VARIOUS DIKE ENCROACHMENTS ON COMPUTED PEAK FLOWS AND LEVELS AT EMERSON 35

FIGURES

FIGURE		PAGE
1	RED RIVER REACHES	5
2	RED RIVER FLOODPLAIN	6
3	TYPICAL RED RIVER VALLEY CROSS SECTION NEAR OSLO, MN	7
4	TYPICAL RED RIVER CROSS SECTION NEAR OSLO, MN.	8
5	BRIDGE SECTION AT OSLO, MN	9
6	WATER SURFACE PROFILES FOR 1979 - DRAYTON TO OSLO.	11
7	SCHEMATIC OF HEC-3 MODEL FOR THE RED RIVER BASIN	15
8	SCHEMATIC OF HEC-5 MODEL FOR THE RED RIVER BASIN	20
9	EXPECTED ANNUAL DAMAGE QUADRIGRAPH	23
10	EXPECTED ANNUAL DAMAGE QUADRIGRAPH FOR LEVEE PLAN.	25

I. INTRODUCTION AND STUDY APPROACH

In October 1980, the International Souris-Red Rivers Engineering Board established the Red River Modeling Task Force to review the four computer models being considered by the U.S. Army Corps of Engineers for modeling the Red River Basin in the United States. These models included: the water surface profile model (HEC-2), the low-flow model (HEC-3), the high-flow model (HEC-5), and the expected annual damages model (EAD). In addition, the task force was instructed to prepare a report on the capabilities of these models for providing data and technical information related to:

a. The impact of existing and proposed river or ring dikes on flow conditions at the international boundary.

b. The impact of existing and proposed works such as reservoir and dike modification on flow conditions at the international boundary.

c. The impact of agricultural drainage on the flow regime at the international boundary.

d. The possibility of an expansion model being developed for the entire Red River Basin.

The Terms of Reference was accompanied by a Plan of Study. Both the Terms of Reference and the Plan of Study are included in the Appendix. The Task Force was instructed to prepare an initial report describing the models and their application as outlined in the objectives for the Board by March 31, 1981. A final report to be prepared by September 1, 1981 would include a description of the Task Force activities, an assessment of the four models, recommendations respecting the application of the models to matters of concern, and any other items that the Task Force considers to be of importance to the modeling of the Red River Basin.

A first draft of the report was provided on April 10, 1981 to the International Souris-Red Rivers Engineering Board.

This report describes the work undertaken by the Task Force to provide the information requested by the Board in the Terms of Reference. The Task Force relied heavily upon users of the four models to provide data for analyzing the capabilities of the models. Model details are presented in Chapter II. In addition, Chapter III briefly presents other studies pertinent to modeling of the Red River Basin. The discussion of the modeling results is presented in Chapter IV. Chapter V lists the conclusions of the Task Force.

The Red River Modeling Task Force was appointed by the Board from Federal, State, and Provincial agencies that had the technical expertise required to carry out all aspects of the Terms of Reference. Membership was as follows:

Canada	United States
R. D. Hofer (Cochairman) Inland Waters Directorate Environment Canada	L. E. Kowalski (Cochairman) St. Paul District U.S. Army Corps of Engineers
F. R. J. Martin Prairie Farm Rehabilitation Administration Department of Regional Economic Expansion	D. A. Sprynczynatyk North Dakota State Water Commission L. D. Seymour Minnesota Department of Natural Resources
R. J. Bowering Water Resources Branch Manitoba Department of Natural Resources	Alternate for L. D. Seymour - O. Sium Minnesota Department of Natural Resources

The Task Force held its first meeting in St. Paul, Minnesota, on November 20, 1980. Five additional meetings were held at appropriate intervals until the conclusion of the studies. Numerous discussions were held with the Corps of Engineers model developers to gain a full understanding of the computer models as they were applied to the Red River of the North. Copies of the meeting minutes were provided to the members of the Engineering Board.

II. MODELS

A. HEC-2 MODEL

1. MODEL DESCRIPTION

The water surface profile model of the Red River of the North is based on the generalized HEC-2 computer program developed at the Hydrologic Engineering Center of the Corps of Engineers at Davis, California.

The HEC-2 computer program is based on the computational method known as the standard step method for gradually varied nonuniform one-dimensional flows both for subcritical and supercritical conditions. The program handles flows through natural streams with tributaries, bridges and culverts, and over dams, weirs, and road tops that are normally encountered in practice. The computation in the standard step method for subcritical flow starts at the most downstream cross section with a known water surface elevation and discharge. The water surface elevation at the next upstream cross section is computed by balancing the one-dimensional energy equation at the two cross sections. The total energy at the upstream cross section is equal to the total energy at the downstream cross section plus the energy loss. The energy loss is due to channel and valley frictional resistance evaluated by Manning's equation and eddy losses resulting from cross-sectional area contractions, expansions, bridges, and culverts. The program evaluates energy losses through bridges and culverts by either normal bridge method or special bridge method depending on whether the structure is submerged.

The HEC-2 computer program has manifold capabilities. The effect of leveed channels, road fills, bridge decks, sediment deposition, and other floodplain encroachments can be determined by the program. Six methods of encroachment analyses can be used. For example, it is possible to specify the encroachment and calculate the stage increase as compared to the existing condition. Alternatively, by specifying the stage increase, the program calculates the corresponding encroachment. The program also has the capability to evaluate channel improvements such as channel dredging and realignment. The program can interpolate cross sections between input cross sections if the difference of the velocity head is too great to accurately determine the energy gradient. The program can simultaneously compute multiple water surface profiles for the main stem and tributary streams. Another capability of the program is to determine the value of Manning's "n" from high water marks and the corresponding discharge. A factor may be inserted to vary the "n" values with stage. The discharge can be changed to account for inflows from tributaries or diversions out of the system.

2. MODEL APPLICATION

This model of the Red River of the North has been used to examine the impacts of flood control projects and floodplain management on water surface elevations. Specific applications have included the analysis of levees, channel modifications, reservoirs, diversions, and floodplain development.

The total model, when completed, will extend from the international boundary upstream to Wahpeton-Breckenridge, a distance of about 394 channel miles. The operational portion of the model extends from the international boundary to Grand Forks. The river system shown on figure 1 is divided into seven reaches. Rating curves from eight U.S. Geological Survey (USGS) gaging stations and recorded high-water marks were used to calibrate the model.

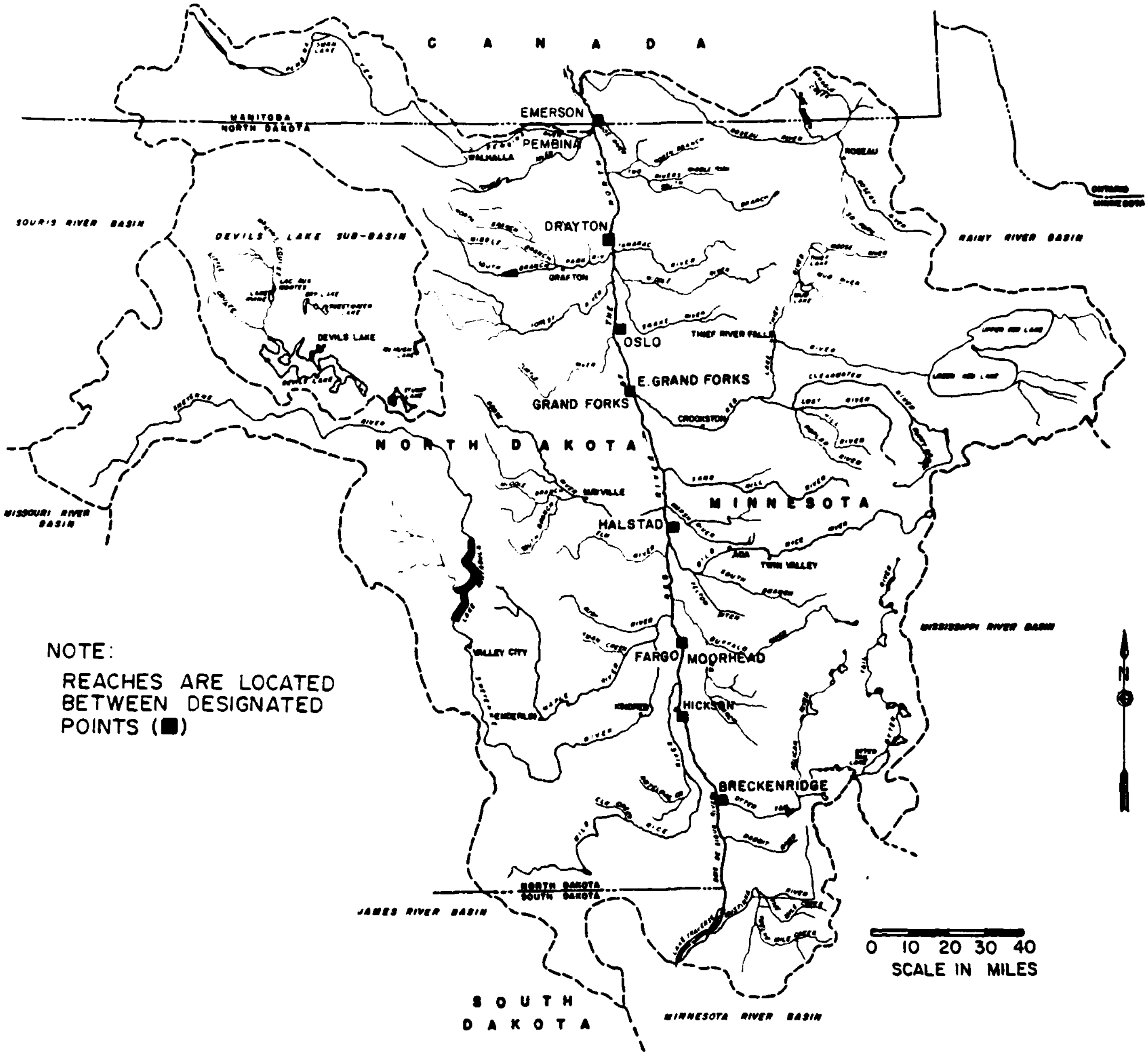
From the international boundary to about Grand Forks, the floodplain is very wide, as much as 10 miles wide at some locations as shown on figure 2. The floodplain is narrower upstream of Grand Forks to the upstream end of the model development area except for an area just upstream of Fargo.

The input data for the model consist of cross sections, bridges, dams, and other floodplain obstructions. About 350 cross sections will be used in the model. Figure 3 shows a sample cross section in the vicinity of Oslo, Minnesota. The actual cross section is about 27,000 feet wide while the water depth in the channel is approximately 30 feet for either the 100-year flood or 1979 flood elevations. Figure 4 shows a blowup of just the channel section and gives a better idea of the representation of the channel and overbank area that is actually coded into the computer model. These figures indicate that a considerable number of points are in the model for each cross section. Note that the existing agricultural levees are also represented in the computer model. Indications of left or right bank are also noted on figure 4. Most of these cross sections were surveyed in either 1978 or 1979 for widths of up to 3 miles. The cross sections were extended to the outer fringes of the floodplain by using USGS topographic maps.

The Red River of the North is spanned by 37 bridges within the model reach area. Survey data for each bridge and the approach roads have been inputted. Figure 5 shows a typical bridge section. Elevations of bridge components are inputted so that all areas that are not effective flow areas are blocked out. Elevations of the approach roads in the floodplain are also inputted. Seven low-head dams are included so that the model can reproduce profiles for small discharges. These seven low-head dams have little impact at large flows, such as the 100-year flow, or the 1979 flood.

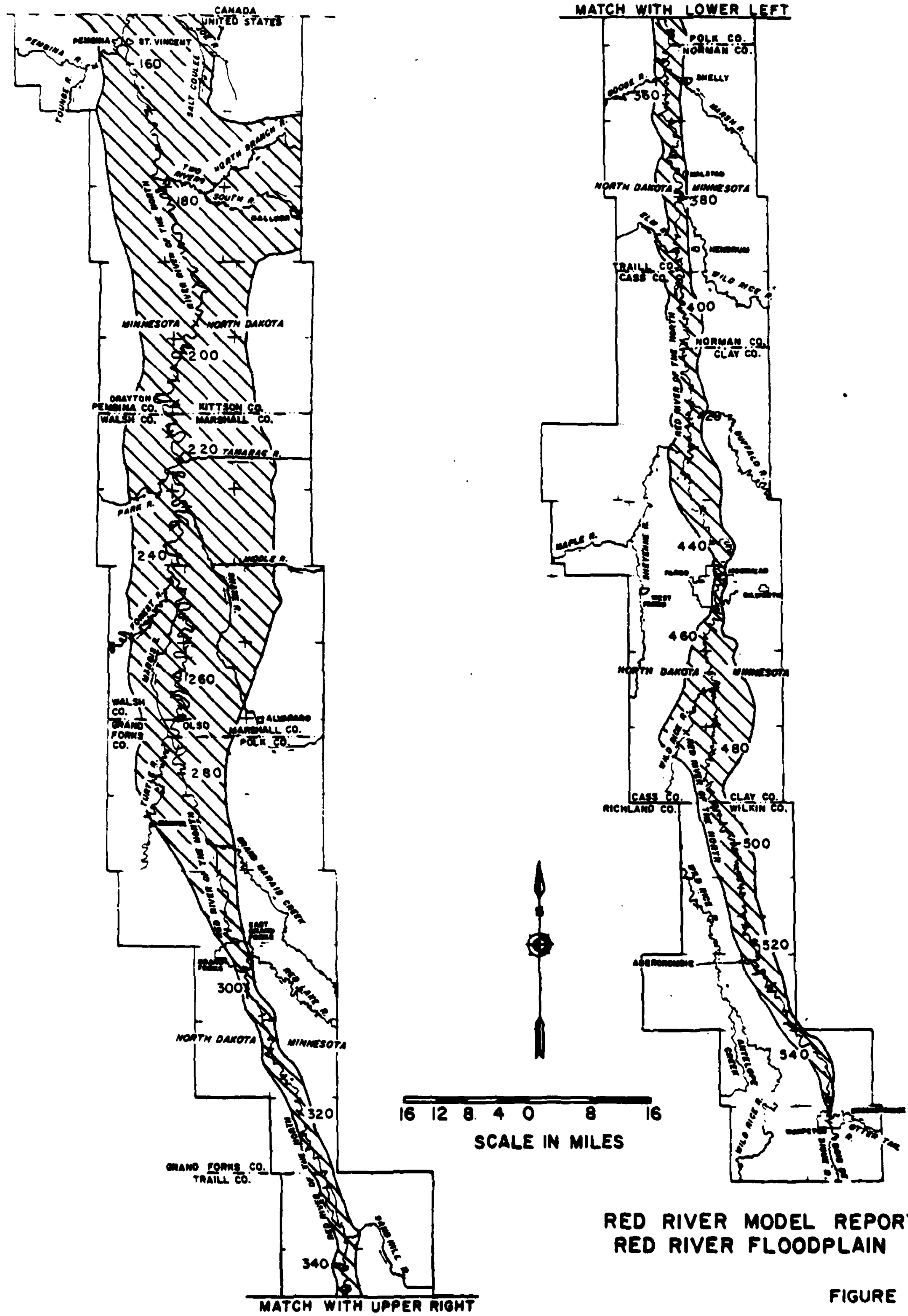
Other floodplain obstructions included in the model are the spoil banks of two existing judicial ditches. These ditches are located on the Minnesota side of the river near the upstream end of the agricultural levees between Oslo and East Grand Forks. Also included are permanent Corps of Engineers levee projects at Pembina, Oslo, Grand Forks, and Fargo. In addition, temporary emergency levees are included at East Grand Forks, Halstad, Fargo, and Grand Forks.

Development of the model has been divided into three different areas. Calibration of the model for the reaches from Canada upstream to Grand Forks was completed in March 1980. Calibration of the reach from Grand Forks to Halstad is under way. The calibration of the reaches from Halstad upstream to Wahpeton-Breckenridge is not presently scheduled. The calibration of



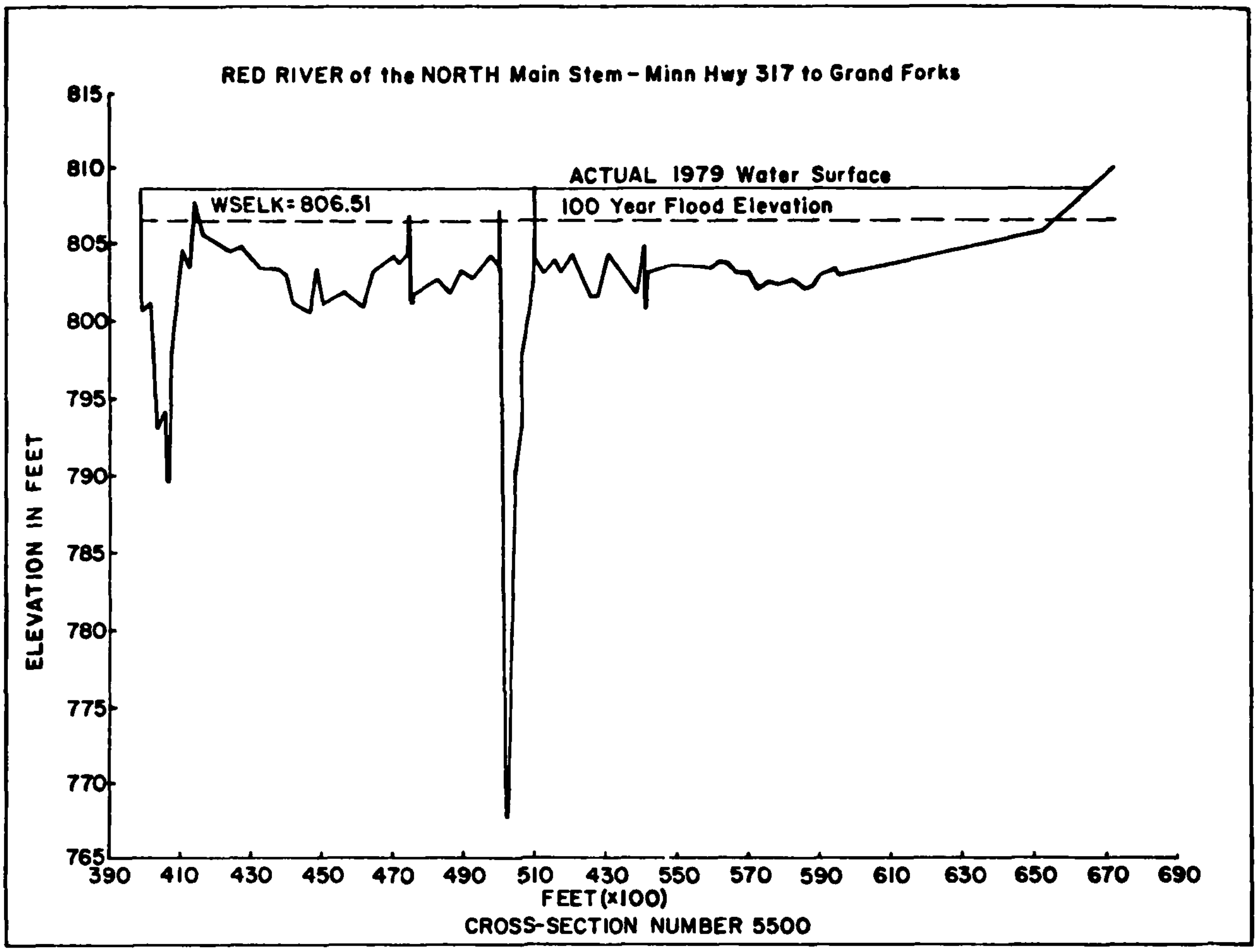
RED RIVER MODEL REPORT
RED RIVER REACHES

FIGURE 1



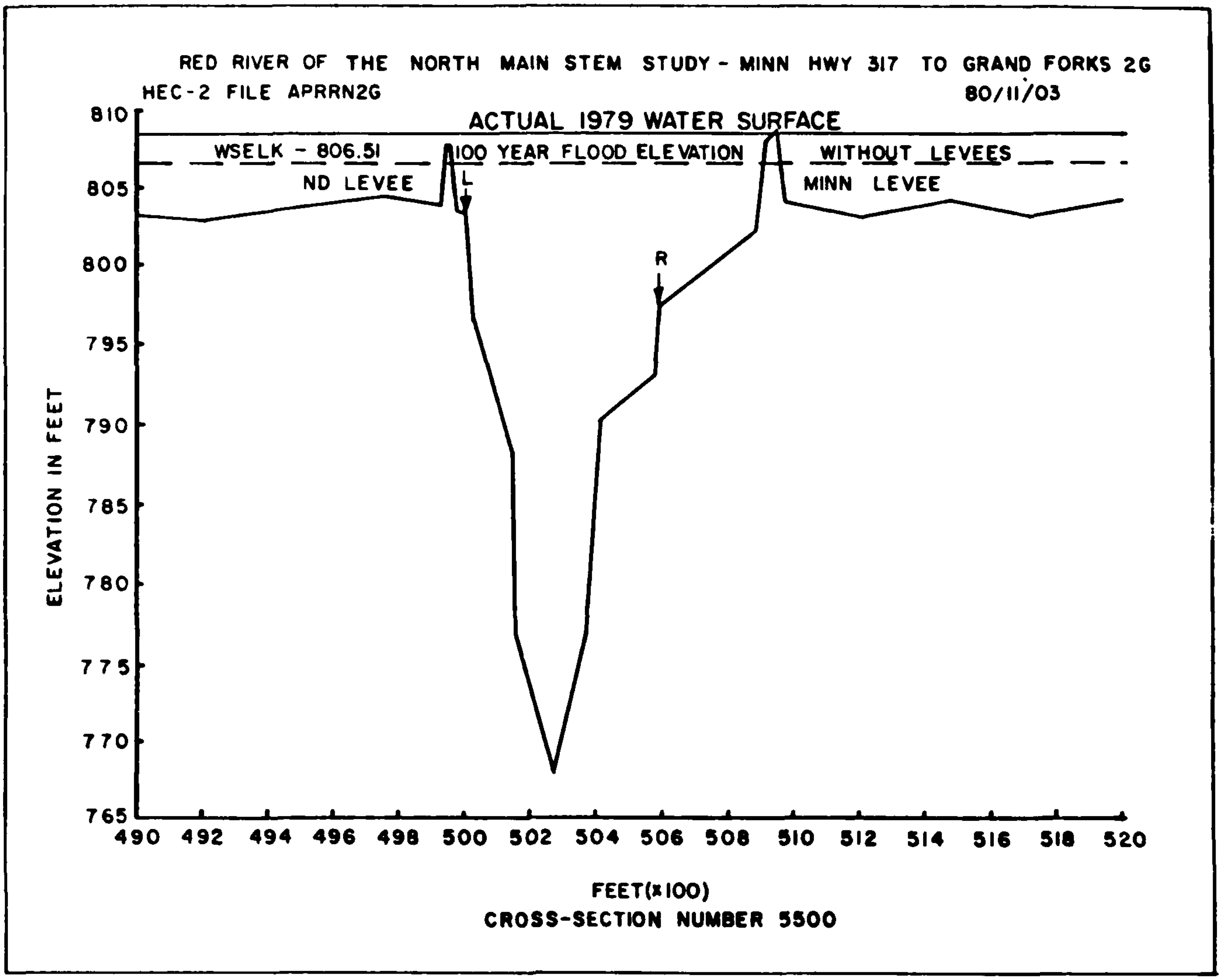
RED RIVER MODEL REPORT
RED RIVER FLOODPLAIN

FIGURE 2



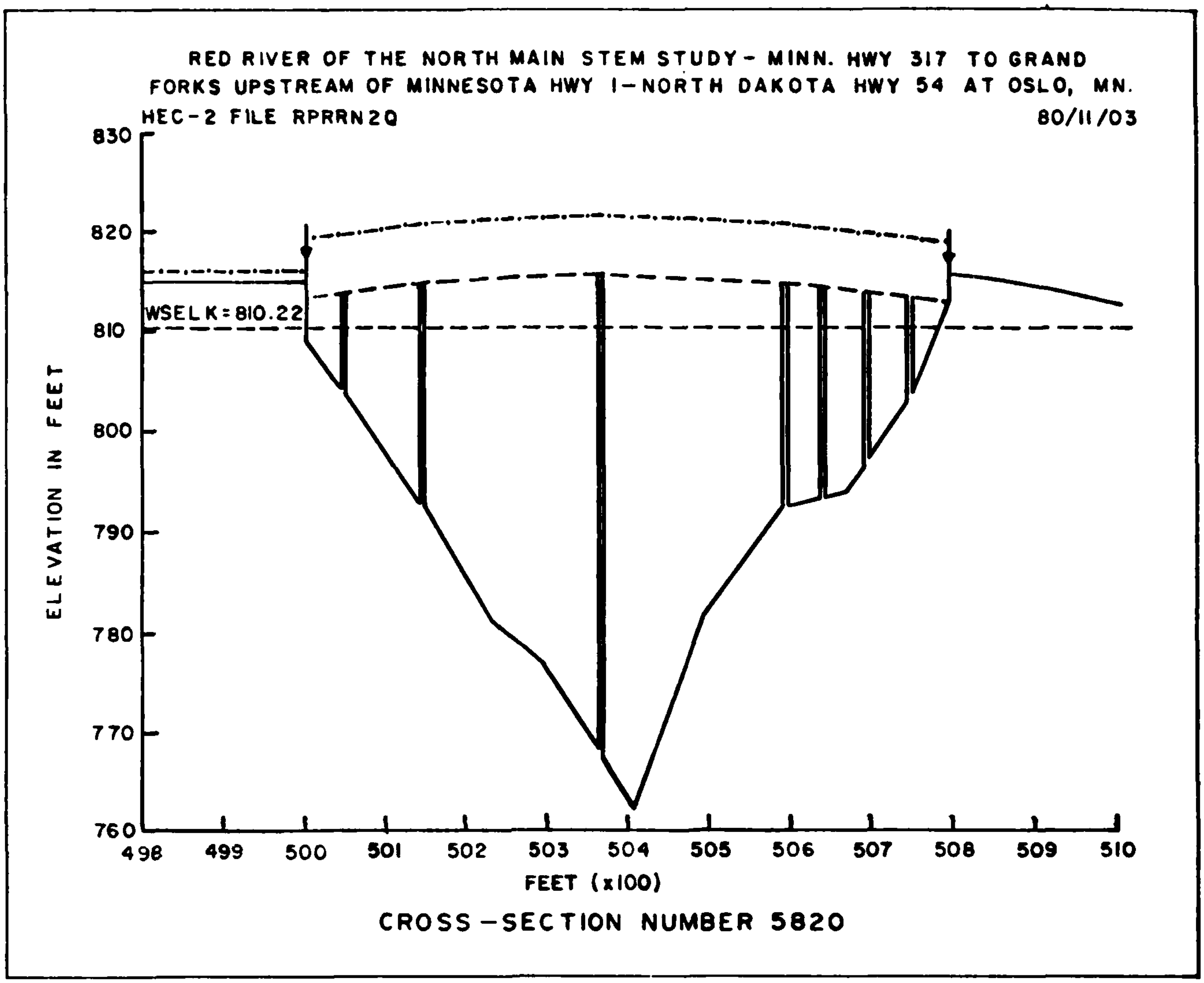
RED RIVER MODEL REPORT
TYPICAL RED RIVER VALLEY
CROSS SECTION NEAR OSLO, MN

FIGURE 3



RED RIVER MODEL REPORT
TYPICAL RED RIVER CROSS SECTION
NEAR OSLO, MN

FIGURE 4



RED RIVER MODEL REPORT
BRIDGE SECTION AT OSLO, MN

FIGURE 5

the existing model included matching most of the existing high-water marks to within 0.3 foot and also utilizing elevation-discharge rating curves at the eight locations previously mentioned. The model for the reach from the international boundary to Oslo was calibrated to the 1969, 1978, and 1979 high-water marks rather than to a flood profile at a particular time. The model for the reach from Oslo to Grand Forks was calibrated using only the high-water marks from the 1969 and 1978 floods. This reach was not calibrated to the 1979 high-water marks because the agricultural levees in this reach were overtopped. The 1969 and 1978 floods had peak discharges at Oslo of about 50,000 cfs. The 1979 flood had a peak discharge at Oslo of about 90,000 cfs. Approximately 70 high-water marks are available for each of the 3 floods.

The calibrated 1979 water surface profile for the reach from Drayton to Oslo is shown on figure 6. The observed water surface profile is also shown.

3. MODEL COST

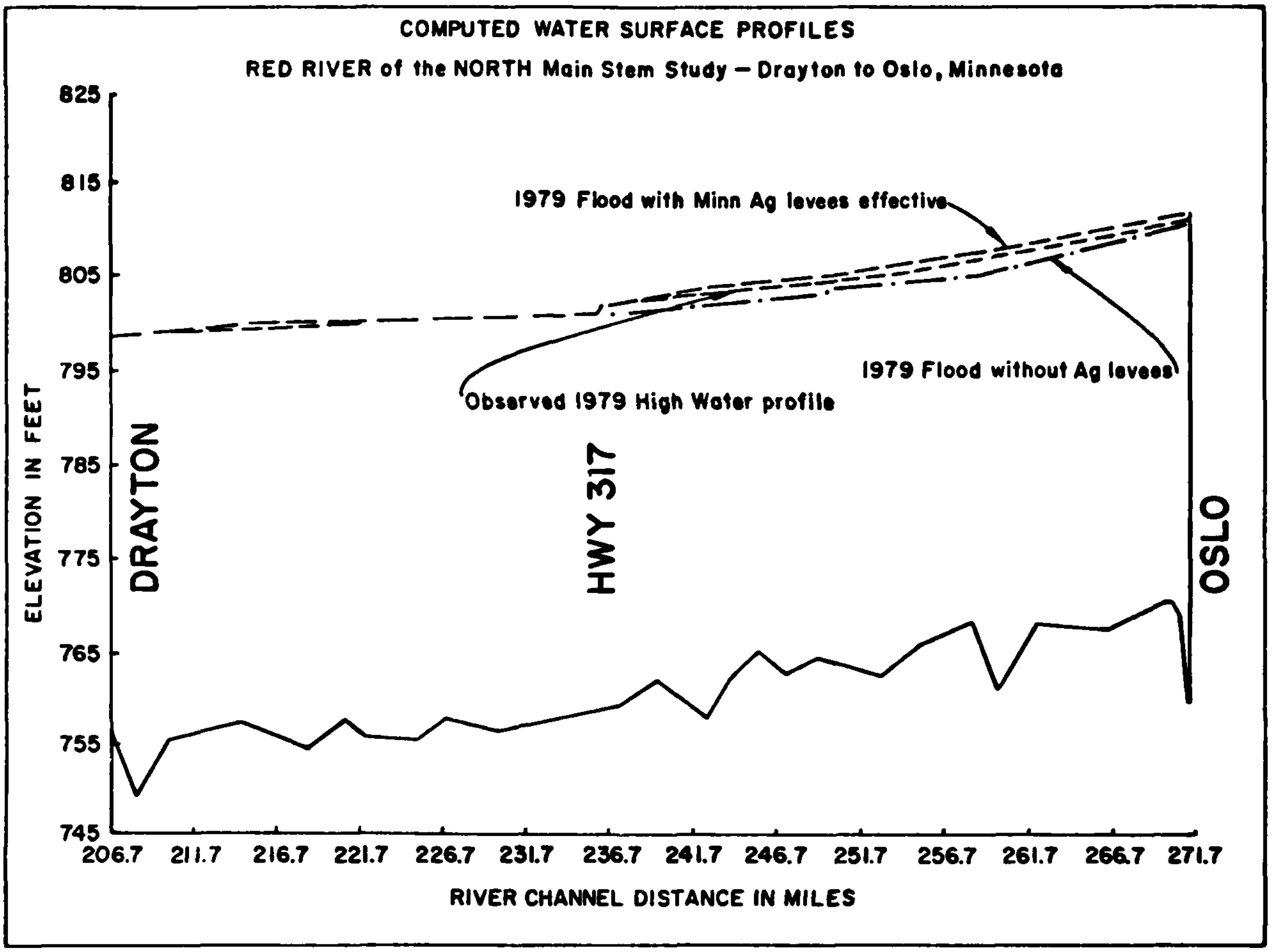
For the existing model the cost of data collection was about $200,000. The estimated cost of calibrating the entire model will be about $100,000. Once the model has been calibrated, the cost of computations is relatively low considering the huge amount of data being processed. The computer costs for calculating a water surface profile for a specific discharge for the 65-mile reach from Drayton to Oslo would range between $5 and $15 depending upon the computer system. To calculate the water surface profile for the entire model reach from the international boundary to Wahpeton-Breckenridge, the cost would range between $30 and $90. This low cost indicates the efficiency of the HEC-2 computer program which is one of the reasons for its wide use.

4. MODEL EXTENSION AND ADAPTABILITY

This model can be extended from the international boundary downstream to Winnipeg. The major work in extending the model would be in collecting data to describe cross sections, bridges, and levees and to calibrate the model for the reach between Winnipeg and Emerson. This cost could be about $50,000 depending upon the amount of existing data. The computer cost to run the extended model from Winnipeg to Wahpeton-Breckenridge would range from $40 to $100.

A single run using the HEC-2 model is limited to a maximum of 300 cross sections. Therefore, the extended Red River model would be run by subreaches just as the existing model is now run.

Future projects in the Red River Basin could be readily studied with the existing HEC-2 model of the Red River Basin. Structural projects other than diking would be constructed on the tributaries of the Red River rather than on the main stem. Since the HEC-2 model includes only the main stem of the river, no changes in cross sections or channel characteristics would be required.



RED RIVER MODEL REPORT
WATER SURFACE PROFILES
FOR 1979 DRAYTON TO OSLO

FIGURE 6

5. MODEL ASSESSMENT

The HEC-2 computer program satisfactorily models a wide variety of flow conditions, is flexible, and is well documented. For these reasons, the program is widely used by government agencies and the private sector.

Although the HEC-2 computer program will adequately model the Red River of the North, two limitations of the program that must be considered during analysis of the river are: (1) the water surface profile cannot be accurately computed for reaches where existing levees are overtopped by flood flows, and (2) encroachments occurring between cross sections (spaced approximately 1 channel mile apart) will require adjustments to the model to evaluate the impact on water surface elevations.

The first limitation occurs because the HEC-2 model is a one-dimensional steady-flow model. The model cannot simulate lateral flows. A significant lateral flow occurs if the levees are overtopped under high-flow conditions and must be accounted for to accurately model the effect of levees on the water surface profile. One analysis was made to determine the maximum levee height that could be tolerated without raising the 1-percent chance flood water surface profile by more than one-half foot. The lateral flows were estimated by using the broad-crested weir formula and assuming the head loss over the levee of 0.1 foot. As a result of these adjustments, the accuracy of the model in dike overtopping situations is reduced.

The second limitation occurs because the cross sections are spaced about 1 mile apart. Therefore, encroachments between cross sections must be adjusted for by either including new cross sections or transferring a cross section to a new location and adjusting that cross section for the encroachment and the floodplain elevation at that location.

6. MODEL ALTERNATIVES

Although other water surface profile models are available, those models were not reviewed because of the suitability of the HEC-2 program.

B. HEC-3 MODEL

1. MODEL DESCRIPTION

The HEC-3 model, "Reservoir Systems Analysis for Conservation," is the fourth generation of a program originally developed in 1965-66 at the Corps of Engineers Hydrologic Engineering Center.

The model simulates the operation of a reservoir system for such conservation purposes as water supply, navigation, recreation, low-flow augmentation, and hydroelectric power. While flood control operations can be handled in some aspects, a more complete simulation is possible using HEC-5, "Simulation of Flood Control and Conservation Systems." The HEC-3 model can accept any configuration of reservoirs, diversions, power plants, and stream control points. Simulations are performed using monthly mean discharge and evaporation data.

The program uses five basic components to model a reservoir system: hydrology, reservoirs, control points, power plants, and diversions. Each component is briefly described as follows:

- Hydrology - The hydrology component requires the specification of inflows, local inflows, and evaporation. Either inflows or local inflows must be defined for each reservoir or control point. Evaporation must be defined for each reservoir.

- Reservoirs - Important physical features of each reservoir are described by specifying elevation, storage, surface area, and outlet capacity relationships. Leakage through or under a dam or powerhouse may also be specified. Operating criteria used in simulating the operation of a reservoir system are expressed in quantitative or mathematical terms. These operating criteria are established by dividing the reservoir into imaginary horizontal levels. For each horizontal level, a reservoir elevation, storage, surface area, and outlet capacity must be specified.

  Each reservoir is operated to meet streamflow targets at specified locations in the system. These operational points are specified for each reservoir by identifying those points for which the reservoir does not operate. Priority of withdrawals from reservoirs serving the same location can be established by specifying additional levels. The highest storage zone is withdrawn from first, then the second highest, and so on down to the lowest, keeping all reservoirs in the system in balance to the extent possible.

- Control Points - Control points are nodes in the river system which can represent river confluences, diversion points, urban centers, or other points of interest. At these control points, water requirements in the form of water demands, or target streamflows, can be specified. Three types of target streamflows may be specified: maximum permissible flow, minimum desired flow, and minimum required flow.

- Power Plants - The model has the capability to analyze power production.

- Diversions - A diversion may exist at any control point and may be specified as the actual flow diverted or as a function of natural flow, regulated flow, or reservoir storage. Diversion requirements may be specified constant for each period or varied each year.

The simulation model operates by considering the water requirements at each control point in the system in a sequential fashion, beginning at an upstream point and moving downstream. The release needed to meet these requirements for all purposes is determined by evaluating each operational requirement and all physical and operational constraints at each site. Also, an index of

the relative state of each reservoir (usually a function of reservoir storage) is determined according to the specified operation guides. After requirements have been met at all control points (or shortages declared if upstream water is not available), "system requirements" are examined to determine whether additional water releases will be needed to satisfy the system demands. If so, the additional needs are proportioned among projects that have been specified to be available for meeting that system requirement in accordance with the relative state of the projects as evidenced by the indices previously computed. The additional releases are added to the previously computed releases for meeting at-site requirements, and the system and at-site requirements are thus met (or system and at-site shortages are declared if water is not available). This process is repeated for each period of the study, with the ending state of the projects in the system for the current period being the beginning state for the next period.

Computations in the model are based on the principle of continuity whereby the change in storage for each reservoir is equal to the difference between inflows and outflows including net evaporation. Results from the successive applications of these computations on a month-by-month basis are recorded for all points in the system by an accounting procedure which accounts for the movement of the water through the system. As these results are calculated, they are stored and printed out, normally a year at a time, on a project-by-project basis, to produce a continuous record of inflow, storage, outflow, power generation, and other pertinent data.

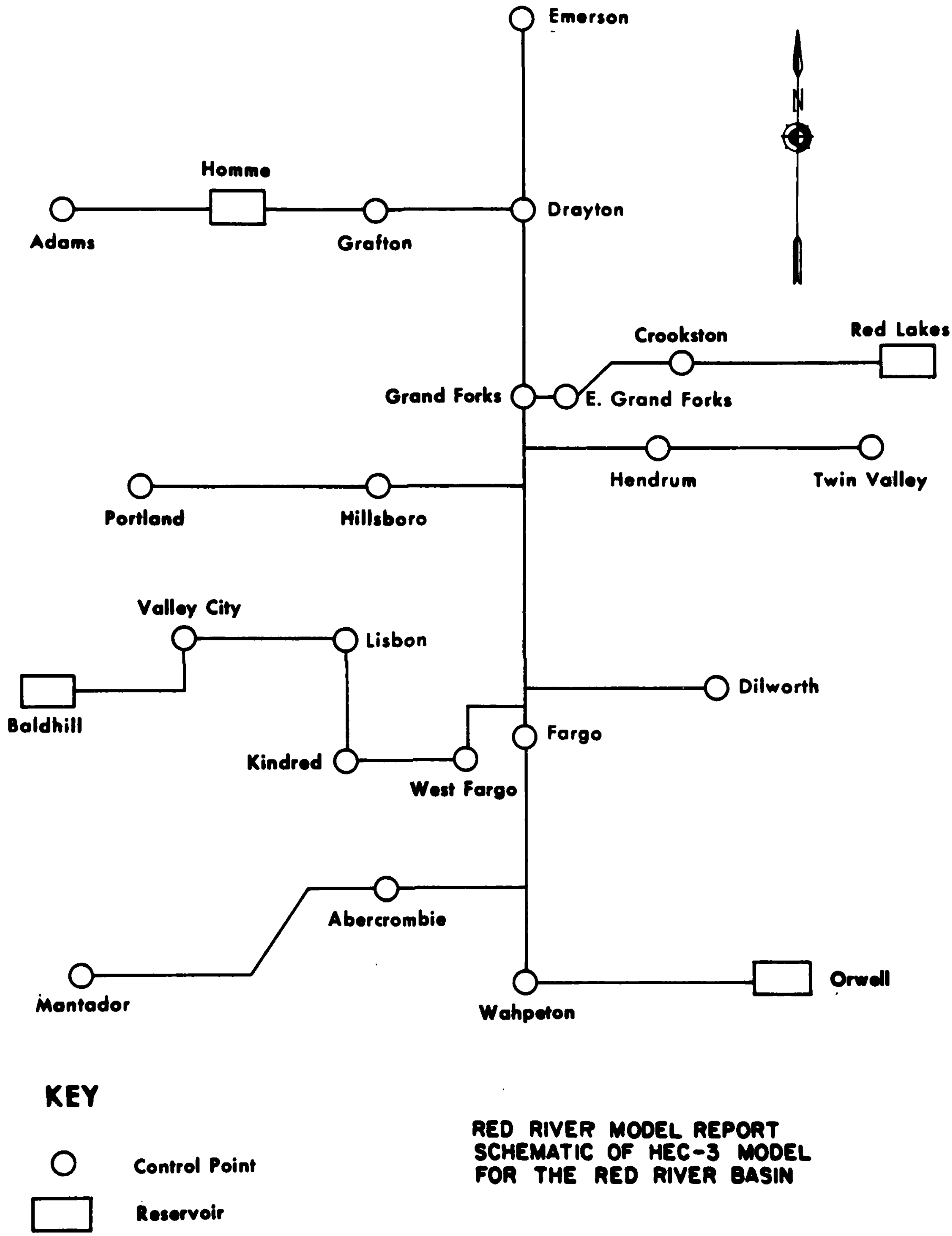
The effect of an existing or proposed project can be determined by simulating the system over a long study period. The effect of any one project can be measured by simulating the operation of the system with and without the project. An additional option is available in the program which assigns economic values to upstream reservoirs. Using this approach, the difference between project and preproject economic values is allocated in direct proportion to the change in storage at the various upstream reservoirs. The most economical plan can be selected by this optimization process.

2. MODEL APPLICATION

The model as applied to the Red River of the North is schematically shown on figure 7. The model will determine the effect on the Red River main stem and tributary flows of reservoir systems used for conservation purposes. The model contains 24 study points consisting of 4 reservoirs and 20 gaging points. The average monthly flows for the period of record, 1930-1976, are included in the model. Presently the model is operational, and has been used to look at water supply problems at Fargo and Grand Forks.

3. MODEL COST

Data acquisition and model development costs have amounted to approximately $35,000. The cost of running the HEC-3 model on the CDC 7600 for the period 1930-1976 is approximately $200 per simulation. The cost of running the HEC-3 model on the CRAY-1 for the period 1930-1976 is approximately $100 per simulation. An update of the data base from 1976 to 1980 would cost an estimated $5,000.



RED RIVER MODEL REPORT
SCHEMATIC OF HEC-3 MODEL
FOR THE RED RIVER BASIN

FIGURE 7

4. MODEL EXTENSION AND ADAPTABILITY

The HEC-3 model could be extended to include the Canadian portion of the Red River basin. The model could then be used to determine the long-term effects of existing and proposed projects within the entire basin.

Extension of the model would cost between $10,000 and $20,000 for data acquisition and model development. The computer costs to run the expanded model would increase the cost proportionately to the number of points added.

The present model includes study points at both existing and proposed reservoir sites and at other points of interest such as hydrometric gaging station locations and major tributary junctions. If study points, other than those presently included in the model, are required in the future, they could be inserted into the model with a minimal amount of effort. Appropriate changes to the input data for the inserted and adjacent study points would have to be made to reflect the changes to the model.

5. MODEL ASSESSMENT

The HEC-3 model provides an adequate evaluation of the effects of existing and proposed storage projects within the Red River Basin.

6. MODEL ALTERNATIVE

The Hydrology Division of the Prairie Farm Rehabilitation Administration (PFRA) is currently using a similar type of low-flow model called the "Multireservoir Water Supply Model." The model, often referred to as the High Speed Model, was originally developed in 1969 for the Saskatchewan-Nelson Basin Board (SNBB) Study and has been extensively modified by the PFRA Hydrology Division. This model uses basically the same methodology as HEC-3, but has some notable differences. It was developed primarily to evaluate water supply alternatives but can be used to evaluate the effects of recreation, low-flow augmentation, navigation, and power generation demands.

For each simulation, the Multireservoir Water Supply Model utilizes four input components: hydrometeorologic data, control point parameters, system configuration, and simulation initiation. Hydrometeorologic data include natural flows at all control points, net evaporations at all reservoir sites, and water uses within the system. The control point parameters, required for each control point, define the capacity, outflow limits, and storage-area relationship. The system configuration provides the control point relationships within the model. The simulation initiation allows an opportunity for redefining parameters or indicators and initiates the model's simulation procedure.

The multireservoir Water Supply Model operates most efficiently if the network is tree-shaped and has no bottlenecks due to small conduit capacities or severe channel restrictions. Bottlenecks make it difficult for the model to effectively utilize available storage.

The model simulates the flow of water through a multireservoir system on a monthly basis. The model begins by examining the entire period of record and computes critical reservoir volumes, which must be protected to meet deliveries immediately below the reservoir, regardless of flow requirements at downstream points. In the step-by-step simulation procedure, these volumes are used to ensure that reservoir releases from upstream subsystems to meet downstream demands will not be unbalanced and result in unnecessary failure to meet minimum flows upstream from confluences. The model does not allow for attenuation due to channel storage or time of travel. That is, water released from an upstream study point is transferred instantaneously to a downstream study point.

The simulation process of the Multireservoir Water Supply Model is similar to the HEC-3 model. In the simulation process, net inflow to each study point is determined, taking into account local inflow and specified uses between the study points. Initial storage volumes are defined for each study point, depending upon specified indicators. The model then simulates operation of the system on a month-by-month basis for a specified period. Evaporation is computed for each time period in the simulation, taking into account the varying reservoir area.

Monthly values of outflow, beginning-of-month reservoir volume, and total system volume are determined by a procedure which accounts for movement of the water through the system. Flows at any study point in the system are determined by adding to the net local inflow the amount of water released from upstream study points. Similarly, reservoir volumes are determined by a water balance involving inflows, outflows, evaporation. losses, and water uses. As the outflows, reservoir volumes, and evaporation are calculated for each control point, the values are stored and displayed a year at a time on a monthly basis.

The cost of a simulation run using the Multireservoir Water Supply Model is apparently less than the cost for a comparable simulation run using HEC-3. For example, a simulation run on an IBM 370 computer for a system of 24 control points, 4 of which are reservoir sites, over the period 1930-1976 would cost approximately $30. However, computer costs for a simulation run cannot be compared directly because the two models have not been run on the same computer system. The cost for obtaining and maintaining a data base would be an additional expense but would be required regardless of which model is used.

The Multireservoir Water Supply Model can be used to model the entire Red River Basin to determine the effects of existing and proposed projects. Basically, it has the same limitations as the HEC-3 model but may provide system simulations at a lower cost. This lower simulation cost would become more important as the number of water supply alternatives increased.

C. HEC-5 MODEL

1. MODEL DESCRIPTION

The flood control model of the Red River of the North is based on the HEC-5 computer program developed at the Hydrologic Engineering Center of the Corps of Engineers at Davis, California.

The HEC-5, "Simulation of Flood Control and Conservation Systems," computer program routes streamflow in a river system by utilizing a kinematic wave technique. The HEC-5 model can be used to determine streamflows throughout the basin for a variety of structural alternatives and flood events. The program may be used for a variety of applications including evaluating the impact of proposed or existing reservoirs on the flood runoff patterns within the river system. The program may also be used for forecasting streamflow runoffs within an existing system. The HEC-5 model can accept many configurations of reservoirs, diversions, power plants, and stream control points.

The maximum number of study features is dependent on the size of the computer. The program uses five basic components to model a reservoir system: hydrology, reservoir and stream routing, control points, power plants, and diversions. Each component is described as follows:

- Hydrology - The hydrology component normally requires the specification of daily inflow at reservoir and control points, although hourly or monthly inflows may be used. Evaporation can be specified on a monthly basis for each reservoir in the system.

- Reservoirs and Routing - Physical features of each reservoir are described by specifying storage, outlet capacity, elevation, surface area, and cost relationships. As noted in the HEC-3 model, simulating the operation of a reservoir system establishes reservoir operating criteria by considering the reservoirs to be divided into imaginary horizontal levels. For each level a reservoir elevation, storage, surface area, and outlet capacity must be specified.

- Each reservoir can be operated independently or in conjunction with several other reservoirs. Individual reservoirs can be operated to minimize floding at downstream control points to meet downstream flow requirements or maintain target levels on reservoirs.

  Reservoir releases can be controlled by a variety of criteria including the following: channel capacity, rate of change of release, maximum allowable reservoir level, emergency releases, balancing tandem reservoirs, outlet capacity, minimum reservoir level, and minimum required flow.

  The program can be used to size proposed reservoirs by determining the amount of storage needed to satisfy water requirements in the system. Reservoir routing with the program is an accounting method which determines the reservoir release to be equal to the

inflow plus or minus the change in storage less evaporation. When the program is used to route flows along a stream, five alternative routing methods are available: Straddle-stagger, Tatum, Muskingum, Modified Puls, and Working R and D. When reservoir releases are routed by nonlinear methods (Modified Puls or Working R and D), linear approximations are used to determine the reservoir releases.

- Control Points - Control points are nodes in the river system which can represent river confluences, diversion points, urban centers, or other points of interest. At these points, flow constraints or target flows can be used to specify the operation of the system.

- Power Plants - The model has the capability to analyze power production.

- Diversions - A diversion may exist at any control point or reservoir and may be specified as a function of flow in the channel or reservoir storage.

2. MODEL APPLICATION

The Corps of Engineers has applied the HEC-5 model to the Red River of the North to examine the effect of reservoirs, levees, channels, and diversions on the flows of the main stem and tributaries of the river.

The model extends from the international boundary upstream to Lake Traverse as shown on figure 8. The model contains 46 control points including 5 reservoirs. Additional data include routing and timing coefficients between control points and hydrometeorologic data for 8 years. These years contain flood events which resulted from several different combinations of snowmelt and rainfall.

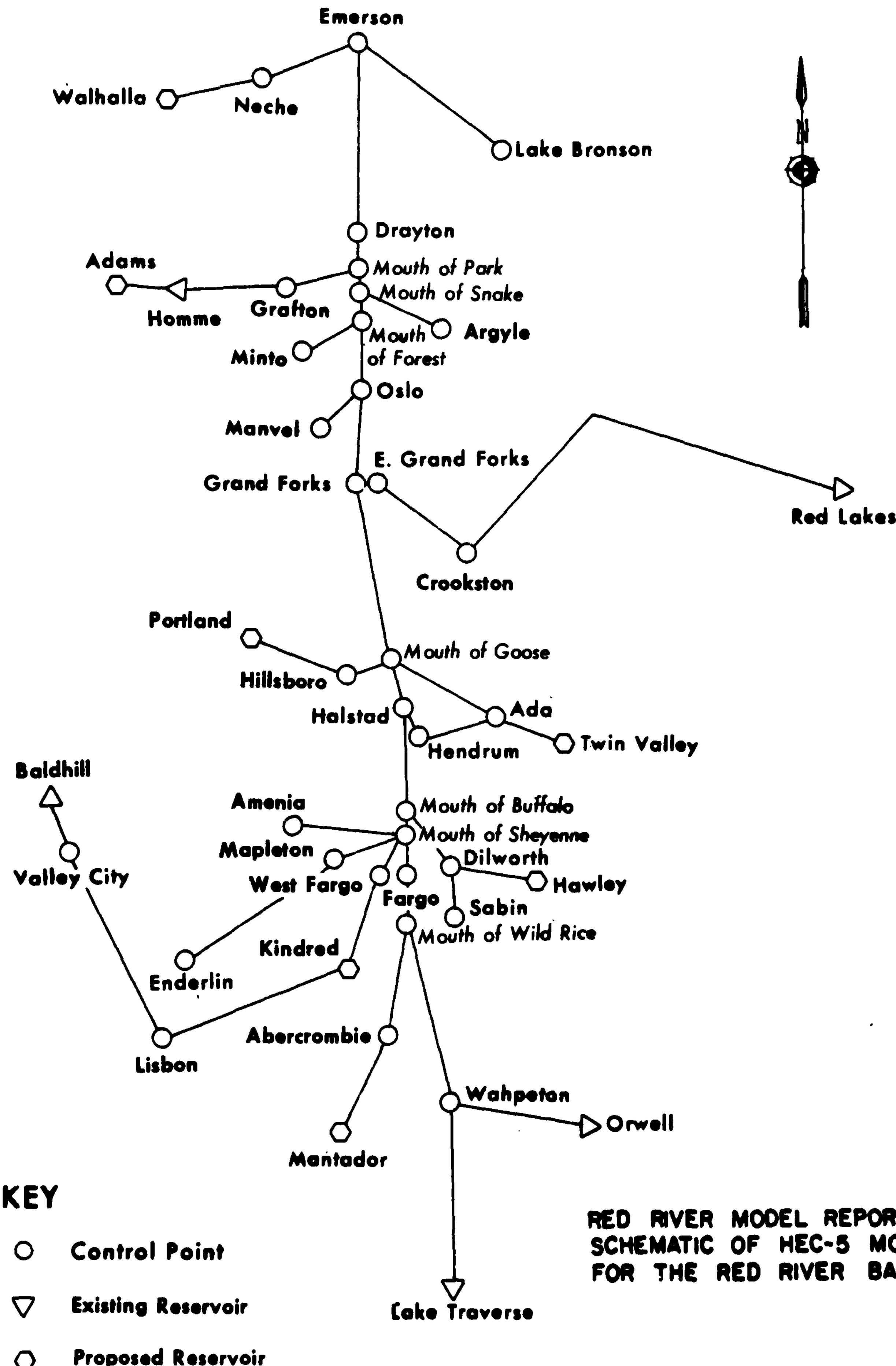
The HEC-5 model has also been used in conjunction with the HEC-2 water surface model to define water level elevations along the Red River of the North.

3. MODEL COST

Data acquisition and calibration costs for the HEC-5 model of the Red River of the North totaled approximately $100,000. To calculate flows for the entire model reach from the international boundary to Lake Traverse would cost approximately $2,000 for 8 years of data. Breaking the model into tributary and main stem components would allow smaller computer runs with corresponding lower costs.

4. MODEL EXTENSION AND ADAPTABILITY

This model can be extended from the international boundary downstream to Winnipeg. A significant amount of background information on routing parameters is already available for the Red River in Canada. The cost to extend the model would be about $5,000. Since this portion of the basin does not contain significant storage reservoirs, the additional computer cost to run the model would range between $10 and $50.



RED RIVER MODEL REPORT
SCHEMATIC OF HEC-5 MODEL
FOR THE RED RIVER BASIN

FIGURE 8

The present model includes study points at both existing and proposed reservoir sites and at other points of interest such as hydrometric gaging station locations and major tributary junctions. If study points, other than those presently included in the model, are required in the future, they could be inserted in the model with a minimum amount of effort. Of course, the model reach between study points immediately upstream and downstream of the inserted study point would have to be recalibrated.

5. MODEL ASSESSMENT

The model satisfactorily simulates streamflows throughout the basin for a variety of structural alternatives and flood events. The HEC-5 model must be used with the HEC-2 model to determine flood elevations. The hydrologic effects of drainage ditches, roads, and wetlands can only be approximated. The model is very large and must be run in segments in order to be accommodated by existing computer facilities. Because of the large amount of data that must be analyzed, the computer costs are relatively high.

The Corps of Engineers is proposing to model tributaries or groups of tributaries of the basin separately to reduce computer costs. Output from these submodels would be inputted to the main stem model.

The Corps of Engineers' routing study was initially done using the Progressive Average Lag option in the HEC-2 model. However, the model was later rerun using the Modified Puls method so that the effect of levee construction could be examined. The present review concentrated on the Modified Puls routings because of the requirement that the Task Force address the model's applicability to indicating the impact of levee construction on flows on the Red River at the international boundary.

The simulation of historic flows at Emerson using average routing coefficients in the Modified Puls routing procedure was not very precise. For example, the simulated peak flow for the 1975 summer flood was 46,900 cfs which is 31.4 percent above the actual peak of 35,700 cfs. The simulated peak flow for the 1979 spring flood was 84,600 cfs, 8.4 percent lower than the recorded peak of 92,400 cfs. Model simulations can be improved by developing the appropriate routing coefficients for each event.

6. MODEL ALTERNATIVES

Several computer models are generally available for river and reservoir routing. Manitoba has developed a routing model called A26HS08T which has been used to route flows from the international boundary to Winnipeg. This model utilizes the Modified Puls method of routing. Modeling of the river system in Canada could also be handled effectively by the Streamflow Synthesis and Reservoir Routing (SSARR) model prepared by the Corps of Engineers and the SIMPAK model prepared by Environment Canada and other river routing programs.

A dynamic wave model (DWOPER) developed by the U.S. Weather Service can compute elevations and flows simultaneously. In addition, it can do automatic calibration, handle lateral flows, and handle rivers with tributaries which have mutual backwater effects.

D. EXPECTED ANNUAL DAMAGE PROGRAM

1. MODEL DESCRIPTION

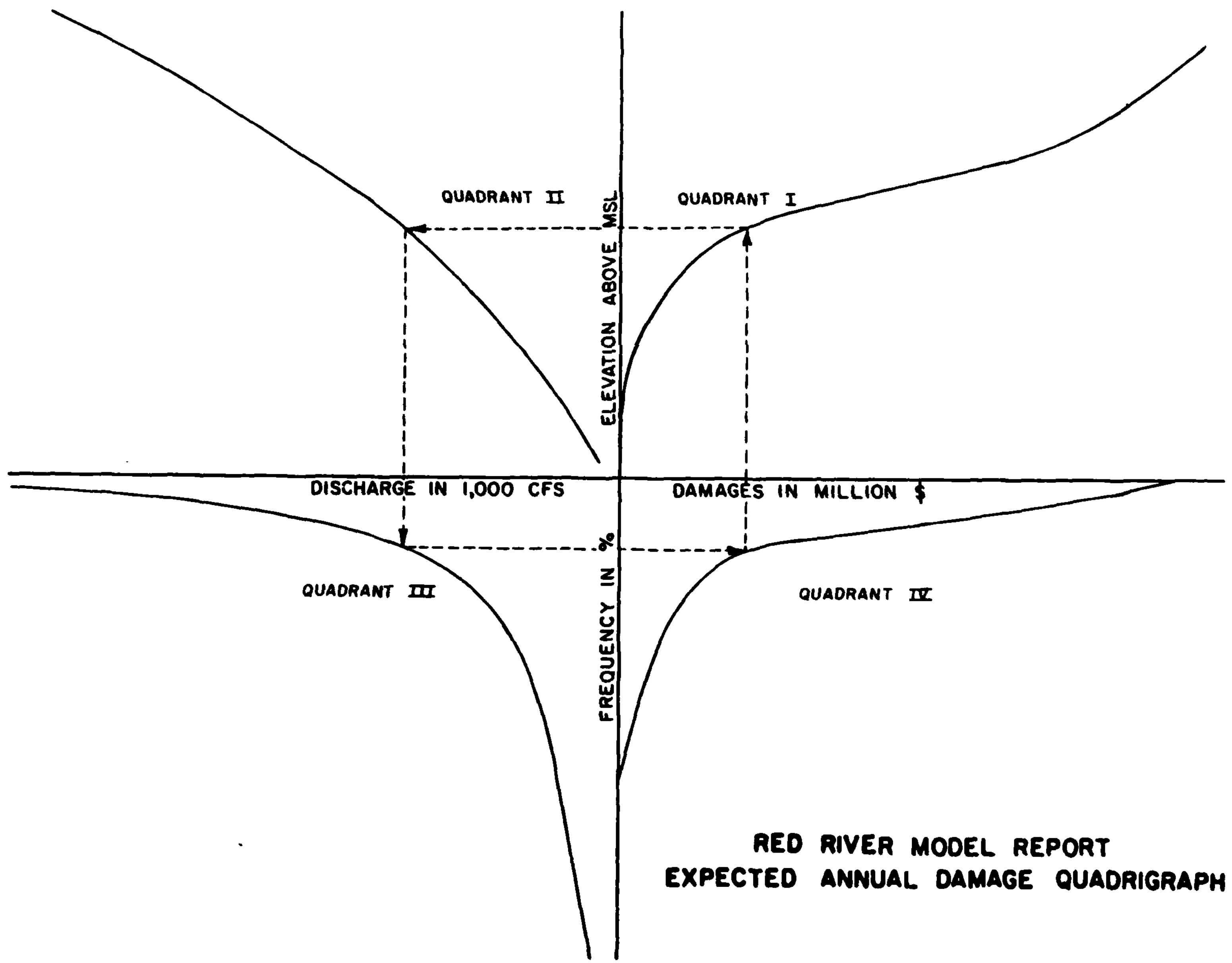
The purpose of the Expected Annual Damage (EAD) Program is to determine the average annual benefits and residual damages for alternative flood control plans. Alternative plans can include levees, diversion channels, channel modifications, reservoirs, nonstructural plans, combinations of all of the above plans, or no action. The program can handle either existing conditions or proposed future conditions, whether future hydraulic, hydrologic, or economic conditions. The program performs damage computations needed for the economic evaluation of floodplain management plans during preliminary plan formulation studies as well as for detailed benefit calculations.

Pertinent program data are input on a reach-by-reach basis. A reach is a section of floodplain that can be represented by the same flow frequency and stage-flow relations. Reach selection is based upon three general criteria: (1) economic criteria, which indicate that similar land use and other like economic factors can be combined within the reach, (2) the study alternatives that will be evaluated, and (3) engineering criteria, such as the advent of tributaries coming in or the significance of structures in the floodplain which may alter rating curve relationships.

In each reach, various damage categories need to be assessed. Damage categories include urban damages, crop damage and other agricultural damage, and transportation damage. Urban damage can be divided into subcategories of residential, commercial, or business and public damages. Other agricultural consists of everything except crop damages and includes farmstead, erosion, weed control, debris, and grain storage on the farm. The fourth category, transportation, is sometimes called road and bridge damages. The program can aggregate these damages by category, by reach, or by both.

Damages are determined for each category by using field surveys. Often, a sampling technique is used rather than a total survey. However, in each case, a relationship between elevation for a historic or hypothetical flood event and a damage, whether actual or hypothetical, is derived for two, three, or four elevations. A zero point of damage is also established on an elevation-damage relationship curve. The economic field survey is used to determine the initial elevation at which damage starts and the various damages which one might expect for various increases in flood elevations.

Input relationship data needed in the program are shown on figure 9. The interaction of the input variables can be explained in discussing this graphic. Quadrant I represents the economic relationship of elevation versus damage computed from the field surveys. Elevation-discharge output from the HEC-2 program is the source for the relationship shown in Quadrant II. The HEC-5 program provides the peak flows for the frequency analysis shown in Quadrant III. The frequency-damage curve given in Quadrant IV is produced by relating the other three curves in Quadrants I, II, and III so that, by starting at any other given point and continuing through each of the quadrants, one always returns to the starting point.



RED RIVER MODEL REPORT
EXPECTED ANNUAL DAMAGE QUADRIGRAPH

FIGURE 9

The area above the curve in Quadrant IV is the graphical representation of average annual damages. The damages in the program will be in dollars except for agriculture where the crop damage is often determined in acres. A conversion factor (a weighted dollar damage per acre figure) is applied to the areas. The program will aggregate by reach or by category and will summarize all urban, all agricultural, or total damages by reach.

An example of the use of the four quadrants is given by figure 10 where all flood damages up to the top elevation of the levee will be prevented.

2. MODEL APPLICATION

The EAD model has been prepared for the Red River of the North from the international boundary to Wahpeton-Breckenridge. The tributaries have not been modeled. The model has been divided into 10 selected reaches based upon economic and hydrologic criteria previously described.

The model has one control point per reach. Current economic conditions and agricultural practices are all related to what is happening hydrologically at specific reach control points. To date, application of the model has been limited to duplication of existing floodplain damage conditions. However, evaluation of the economic effects of agricultural farm levees is planned for 1981. Other uses are also anticipated. Wide use could follow, particularly if the Corps should establish a technical resource center for the Red River of the North.

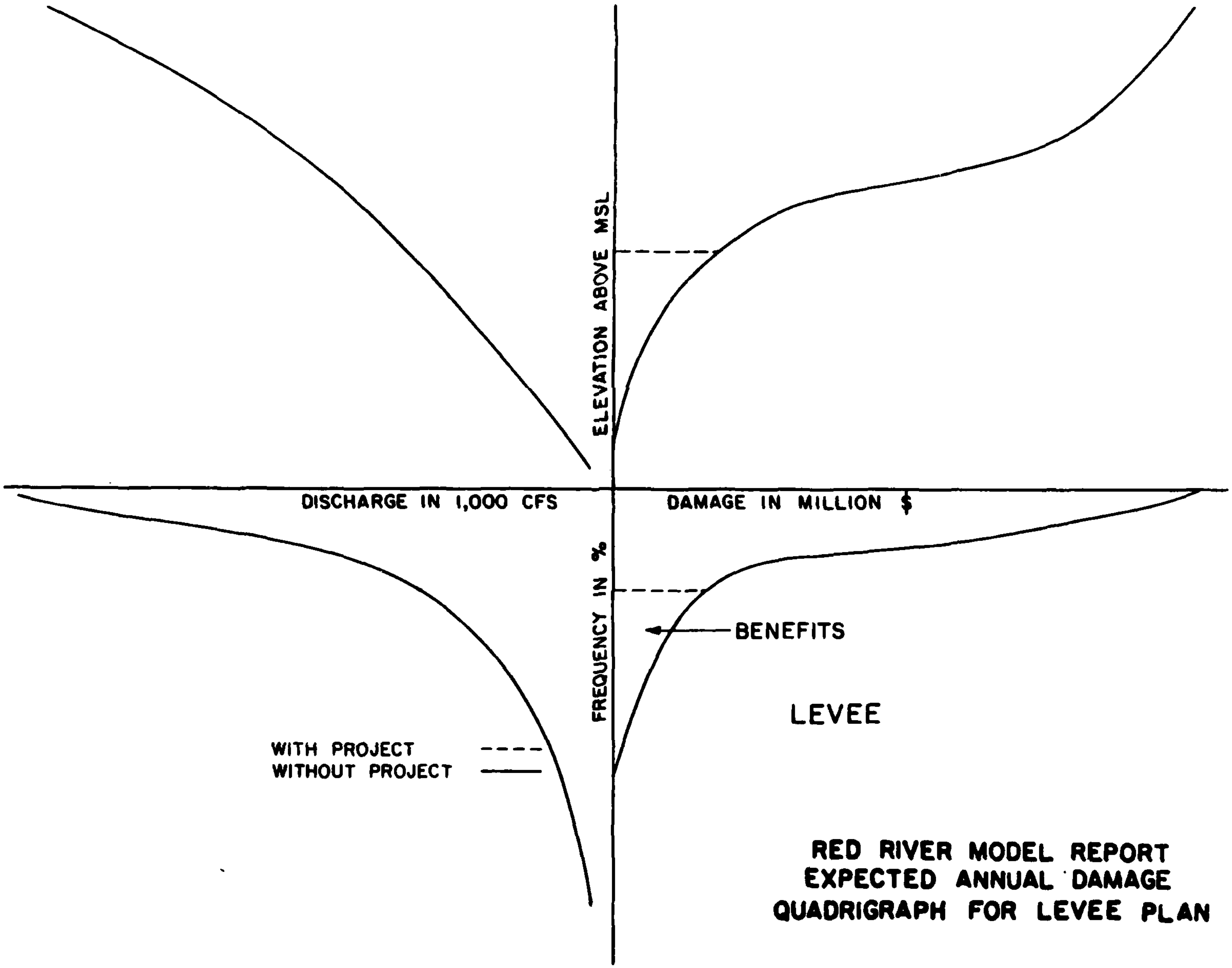
3. MODEL COST

Four categories of costs are associated with an EAD model: data acquisition costs, model calibration costs, model run costs, and data base update costs. Data acquisition costs will vary with the size of the study area. The data acquisition costs for the 10 reaches on the Red River main stem approximated $20,000.

Model calibration costs are the second most significant cost factor. Calibration costs approximated $5,000. Once the model is calibrated, per run costs range between $200 and $500, varying with the size of the model. Future use of a model would require updates of economic data. Land use changes in all damage categories should be incorporated every 2 to 3 years. This cost would probably not exceed 25 percent of the original data acquisition costs.

4. MODEL EXTENSION AND ADAPTABILITY

Extending the EAD model into Canada would be very straightforward. The Canadian tributary basins to the Red River could be incorporated into such a model expansion. Should the model become too large, it could be broken at any point since inputs are not interdependent by reach.



RED RIVER MODEL REPORT
EXPECTED ANNUAL DAMAGE
QUADRIGRAPH FOR LEVEE PLAN

FIGURE 10

The EAD model could easily be used to determine the impact of future projects in the Red River Basin. The only required change would be in Quadrant III where the peak flow frequency curve is given. This curve would have to be modified in accordance with revised flood routings.

5. MODEL ASSESSMENT

The EAD Program will compute the economic consequences of a wide range of structural and nonstructural alternatives. The influences of levees, diversion structures, channel modifications, storage reservoirs, nonstructural plans, agricultural drainage, and other conditions are all handled well by an EAD Program model. If the hydraulic and hydrologic conditions can be analytically determined, then the average annual expected damages and benefits can also be computed by the program.

The EAD Program does not have the capability for directly considering the effect of timing and duration of flooding in computing agricultural damage. The average weighted damage per acre based upon the flood history pattern must be independently derived.

6. MODEL ALTERNATIVES

Alternative models are available to determine expected annual damages. An agricultural damage program called "The Computerized Agricultural Crop Flood Damage Assessment System" was developed by the Vicksburg District office of the Corps of Engineers. This model can handle a multitude of cropping variables which affect damage prediction throughout the growing season. Average annual damage per acre is calculated from a summary of current values for damages for historic events. While the Vicksburg District's program is not an alternative to the EAD Program, it may be desirable to use both while modeling the Red River of the North.

The Water Resources Branch of the Province of Manitoba has developed an agricultural damage model which is somewhat similar to the model developed by the Vicksburg District. The Water Resources Branch model requires that the river basin be divided into reaches and that flooded area-discharge relationships be developed for cultivated land, native forages, and pastureland in each reach. Damages are then computed for each crop type in each reach by considering the per-acre damage costs as a function of date and duration of flooding. The model will estimate damages for five different cropping situations: spring flooding of cultivated land, spring flooding of pastureland, summer flooding of cultivated lands, summer flooding of native forages, and summer flooding of pastureland. This model has been successfully applied to numerous basins in Manitoba for estimating average annual agricultural damages under a variety of flow conditions. However, the model is restricted to the computation of agricultural damages. It does not address urban, farmstead, and other damage categories.

III. OTHER STUDIES

A. CH_2M HILL REPORT - ANALYSIS OF EXISTING HYDROLOGIC MODELS, RED RIVER OF THE NORTH DRAINAGE BASIN, NORTH DAKOTA AND MINNESOTA

The States of North Dakota and Minnesota requested the St. Paul District of the Corps of Engineers to investigate possible causes of increased flood damages in the Red River of the North Basin. It has been suggested that the increase in flood flows may be related to the common practice of draining farmland for increased agricultural productivity. The Corps of Engineers contracted with CH_2M Hill to evaluate existing hydrologic models and to determine which of them would be best suited to an analysis of the causes of possible increased flooding on the Red River of the North.

CH_2M Hill investigated 36 hydrologic models, of which only 13 models were found to have a majority of the following characteristics determined to be necessary for modeling the Red River Basin:

- Ability to simulate the snowmelt and rainfall runoff of the Red River of the North due to snowmelt and rain with snowmelt from both small and large drainage areas.

- Ability to simulate the storage effects of wetlands and depressions.

- Ability to simulate the effects of surface drainage projects.

- Ability to route flows in the tributaries and the main stem.

- Methodologies based upon proven hydrologic and hydraulic principles.

- Successful applications to similar watersheds.

- Readily available with data requirements which are not excessive.

- Incorporate a continuous moisture balance so that assumptions do not have to be made regarding antecedent soil moisture prior to a storm.

- Ability to simulate runoff events and analyze alternatives at a reasonable cost.

The report contains a detailed description of each of the 13 models.

The investigation concluded that 3 of the 13 models held the greatest promise for meeting the Red River of the North modeling requirements. These three models included the Hydrocomp Simulation Program Fortran version (HSPF), the Runoff and Routing Model (RROUT), and the Minnesota Model for Depressional Storage (MMDW).

The three subbasin models were further investigated and compared to determine their ability to thoroughly analyze depressional and wetland hydrology, their adaptability to large and small watersheds in the Red River of the North Basin, and their respective data requirements. The report concludes that the MMDW includes the most direct analysis of depression storage. However, the report further concludes that the model's extensive data requirements and limited application history reduce its usefulness. RROUT and HSPF are very similar, and either of them could be applied to an analysis of flooding in tributaries of the Red River of the North. RROUT's selective storm routing and analysis are less expensive than HSPF's analysis of all events. Therefore, the report selected RROUT as the preferred model for a proposed study of the Red River of the North and its subbasins.

Assuming that either HSPF or RROUT would be chosen for modeling the subbasins, the report reviews data requirements for modeling to be initiated in the Rush River subwatershed. Most required data appear to be readily available. Only calibration data, detailed streamflow records, and basin specific precipitation data and stream channel data would have to be field collected. Guidelines for collecting the necessary data and for data reduction prior to model input are presented in the report.

B. UNITED STATES GEOLOGICAL SURVEY - STUDY OF CHANGES IN HYDROLOGIC RESPONSE OF THE RED RIVER OF THE NORTH

The Souris-Red-Rainy Regional Committee of the Upper Mississippi River Basin Commission has begun to study the possible effect of drainage on flood peaks on the Red River of the North. This study is being done as a result of public concern that the large floods in recent years are direct results of drainage within the watershed.

In the first phase of the study, the USGS will develop information on the extent of changes in the hydrologic response of the basin. The objectives of this phase are to: (1) provide background information on changes within the river basin; (2) document changes in hydrologic characteristics with respect to flood peaks; (3) based on the results of the first two objectives, make recommendations for further study in determining the effect of drainage on flood peaks.

The project study area will include the entire Red River Basin in the United States, as well as some additional basins outside the Red River Basin. Data from outside the basin will be used to establish a hydrologic base to determine changes within the basin. The determination of flood frequency changes and climatic changes on the Red River will provide documentation of the changes that have occurred due to man's activity in the river basin. Only available data will be analyzed. The USGS study is scheduled for completion during 1981.

C. MANITOBA FLOOD FORECASTING STUDY

In April 1981 the Governments of Canada and Manitoba entered into a joint study to improve the flood forecasting system for the Red, Assiniboine, and Souris Rivers in Manitoba. The severe flooding in the Red River Valley in the spring of 1979 reemphasized the importance of accurate and timely flood forecasts, both before and during flood periods.

Over the years the Manitoba Water Resources Branch has developed forecasting procedures for most of the major rivers in southern Manitoba. Although these have provided reasonably accurate forecasts in the past few years, improvements in accuracy would reduce flood damages by providing more warning time for implementation of emergency activities, including dike construction and moving of transportable items.

Scheduled to take 5 years, the new agreement will be carried out in two phases. In the planning and design phase, a pilot project will be conducted on the Boyne River Basin to test a variety of forecasting models. Based on the results of this pilot project, the most applicable of these models would be calibrated to provide forecasts for the Red, Assiniboine, and Souris Rivers. Also during the first phase a flood forecasting center will be established in Winnipeg and the necessary equipment will be installed for monitoring flows at key locations in the three river basins.

At the end of Phase I the steering committee would assess the results of Phase I and determine whether the developed procedures would provide significantly better forecasts than present forecasting methods. If the results are promising, the steering committee would recommend proceeding with Phase II which would involve the implementation of operational flood forecasting procedures for the Red, Assiniboine, and Souris Rivers.

All costs of the study will be jointly shared by both governments to a total cost of $600,000.

IV. MODELING RESULTS

The Task Force reviewed the four computer models being used by the Corps of Engineers for modeling the Red River of the North basin in the United States. The Task Force examined the modeling principles of the four models and the simulations made by the Corps of Engineers using the HEC-2 and HEC-5 models. Simulations for the HEC-3 and EAD models were not reviewed because they were not required to respond to the terms of reference. The following sections discuss the results of the HEC-2 and HEC-5 simulations.

A. HEC-2 MODEL

The HEC-2 and HEC-5 models were used together to simulate the progression of flows with the corresponding high water surface profiles along the river system. In the most recent version of the HEC-5 model, the Modified Puls routing method was applied so that the effect of loss of storage because of the agricultural dikes could be assessed on flood peaks. Table 1 provides a summary of the HEC-2 modeling runs that have been made for 1969, 1978, 1979, and the 1-percent chance flood for the Red River of the North.

The computed 1969 elevations closely approximated the observed 1969 water levels. A maximum difference of 0.12 foot was obtained at mile 285. In 1969, dikes had not yet been constructed along the Red River in the vicinity of Oslo.

The HEC-2 model was used for the 1978 flood event to compute the water surface profile for the observed flows along the river. Table 1 indicates a maximum difference occurred at Oslo where the computed water level was 0.34 foot lower than the observed water level. The dikes were effective during the 1978 flood. The HEC-5 model was not run for 1978 because of insufficient data.

The water surface elevations for 1979 were not computed above mile 236 (downstream end of dikes) as shown in Table 1 since the dikes were breached or overtopped and therefore not effective during this flood.

For comparative purposes, the Corps of Engineers examined the 1-percent chance flood for no encroachments, for encroachments which would raise the 1:100 water level by 0.5 foot (Condition 1) and for encroachments that would contain the flow within the channel or existing diked sections (Condition 2). The diking for Conditions 1 and 2 was assumed to extend the entire length of the reach between Grand Forks and Emerson. As shown in Table 1, Condition 2 would raise the water level at several locations significantly above the water level that would occur with no encroachments. The greater increase would be slightly over 16 feet at river mile 258.

Table 1 - Summary of HEC-2 modeling runs, Red River of the North, Grand Forks to Emerson

Location	1969 Elevation (feet) Observed	1969 Elevation (feet) Computed	1969 Δ	1969 Observed flow (cfs)	1978 Elevation (feet) Observed	1978 Elevation (feet) Computed	1978 Δ	1978 Observed flow (cfs)	1979 Elevation (feet) Observed	1979 Elevation (feet) Computed	1979 Δ	1979 Observed flow (cfs)	1-percent chance flood: No encroachments Elevation (feet)	Condition 1 (3) Average top width (feet)	Condition 1 (3) Elevation (feet)	Condition 1 (3) Δ Elevation (feet)	Condition 2 (4) Average top width (feet)	Condition 2 (4) Elevation (feet)	Condition 2 (4) Δ Elevation (feet)	Condition 2 (4) Flow (cfs)
Emerson	787.61	787.61	0	54,700	785.80	785.80	0	50,300	791.30	791.30	0	92,400	791.75	20,000	792.25	0.50	375	792.25	0.50	109,000
Drayton	796.36	796.38	+.02	56,600	796.29	796.28	-.01	56,200	798.70	798.69	-.01	91,000	798.70	18,000	799.28	0.55	1,227	808.30	9.57	99,000
Mile 236	798.86	798.83	-.03	53,900 (1)	800.52	800.45	-.07	55,000 (1)	801.42	(2)		91,300 (1)	800.73	22,000	801.23	0.50	857	814.32	13.59	94,000 (1)
Mile 258	804.00 (1)	804.04	+.04	53,400 (1)	805.80 (1)	805.78	-.02	53,900 (1)	806.50 (1)	(2)		91,200 (1)	804.79	25,000	805.32	0.53	981	821.06	16.27	93,500 (1)
Oslo	809.57	809.51	-.06	50,300	810.56	810.22	-.34	53,200	811.25	(2)		91,000	810.35	22,000	810.97	0.62	611	826.21	15.86	91,000
Mile 285	817.12	817.00	-.12	53,400 (1)	817.80 (1)	817.70 (1)	-.10	54,100 (1)	819.00 (1)	(2)		81,000 (1)	820.70	20,000	821.24	0.54	384	836.09	15.39	89,000 (1)
Grand Forks	824.04	823.96	-.08	53,400	823.97	824.28	+.31	54,100	827.16	(2)		81,000	829.00	16,000	829.53	0.53	960	841.11	12.11	89,000

(1) Interpolated or derived synthetically.
(2) Not computed due to levee overtopping conditions.
(3) Condition 1 refers to encroachments that would raise 1:100 water levels by one-half foot.
(4) Condition 2 refers to encroachments that would limit flow to the main channel or existing dike positions. Flows were not increased to account for the reduction of channel storage.

B. HEC-5 MODEL

Table 2 provides a summary of HEC-5 modeling runs that have been made for 1969 and 1979 floods in the Red River of the North Basin. The flood peaks for the 1-percent chance flood are also shown in Table 2 for comparative purposes. The HEC-5 model was initially applied to the 1948, 1950, 1965, 1966, and 1969 flood events. Later the 1975, 1978, and 1979 events were also simulated.

The 1969 and 1-percent chance floods have essentially the same floodplain conditions in that no dikes were present. However, the floodplain does contain roads and other flow obstructions. By 1979, extensive dikes were constructed on both sides of the river in the vicinity of Oslo. However, the 1979 flood overtopped the dikes that were in existence at that time.

The HEC-5 simulation of the 1969 flood yielded a computed flow of 65,200 cfs at Emerson which was 10,500 cfs (19.2 percent) larger than the observed flow of 54,700 cfs. The HEC-5 simulation of the 1979 flood yielded a computed flow of 84,600 cfs at Emerson which was 7,800 cfs (8.4 percent) smaller than the observed flow of 92,400 cfs. The 1-percent chance flood peak of 109,000 cfs at Emerson would be 16,600 cfs (18.0 percent) larger than the 1979 flood peak of 92,400 cfs.

Table 3 summarizes additional HEC-5 runs made by the Corps of Engineers. The results shown in Table 3 provide a comparison among the three conditions for each of the 1969 and 1979 floods. For comparative purposes the computed flows for existing conditions were utilized rather than observed flows. The diking for Conditions 1 and 2 was assumed to extend for the entire length of the reach between Grand Forks and Emerson.

Under the 1969 flood event the peak flows would increase from 65,200 cfs at Emerson to 66,700 cfs (+2.3 percent) under Condition 1 and 81,800 cfs (+25.5 percent) under Condition 2. For 1979, the peak flows for Condition 1 would increase from 84,600 cfs to 86,600 cfs (+2.4 percent) while the peak flow for Condition 2 would increase from 84,600 cfs to 110,700 cfs (+30.9 percent).

The impacts of various dike encroachments (including the no encroachment condition) on computed peak flows and water levels at Emerson are presented in Table 4 for the 7 years that were modeled. In these 7 years, Condition 1 would increase the flow by an average of 1,600 cfs and the water level by an average of 0.18 foot at Emerson. Under Condition 2, the flow and water level at Emerson would increase by averages of 18,000 cfs and 1.59 feet, respectively.

Table 2 - Summary of HEC-5 modeling runs, Red River of the North, Grand Forks to Emerson

(All flow in cfs)

Location	1969			1979			1-percent chance flood with no encroachment (3)
	Observed (1)	Computed (2)	Δ	Observed (1)	Computed (2)	Δ	
Emerson	54,700	65,200	+10,500	92,400	84,600	-7,800	109,000
Drayton	56,600	54,100	-2,500	91,000	84,300	-6,700	99,000
Mile 236	-	51,600	-	-	81,800	-	94,000
Mile 258	-	51,400	-	-	80,700	-	93,500
Oslo	56,200	51,200	-5,000	-	80,300	-	91,000
Mile 285	-	51,500	-	-	80,600	-	89,000
Grand Forks	53,400	51,700	-1,700	80,900	80,900	0	89,000

(1) Observed flows are actual USGS measurements.
(2) Flows were computed by Modified Puls routing.
(3) No encroachment refers to predike conditions but contains roads and other structures.

Table 3 - Sensitivity analysis for HEC-5 model, Red River of the North, Grand Forks to Emerson

Location	1969 flow in cfs: Computed for existing conditions(1)	1969 Condition 1(2): Computed	1969 Condition 1(2): Δ	1969 Condition 2(3): Computed	1969 Condition 2(3): Δ	1979 flow in cfs: Computed for existing conditions(1)	1979 Condition 1(2): Computed	1979 Condition 1(2): Δ	1979 Condition 2(3): Computed	1979 Condition 2(3): Δ
Emerson	65,200	66,700	+1,500	81,800	+16,600	84,600	86,600	+2,000	110,700	+26,100
Drayton	54,100	55,700	+1,600	62,700	+8,600	84,300	85,000	+700	100,700	+16,400
Mile 236	51,600	52,900	+1,300	55,800	+4,200	81,800	82,000	+200	89,800	+8,000
Mile 258	51,400	52,800	+1,400	55,200	+3,800	80,700	80,700	0	88,100	+7,400
Oslo	51,200	52,100	+900	53,000	+1,800	80,300	80,300	0	84,100	+3,800
Mile 285	51,500	-	-	-	-	80,600	-	-	-	-
Grand Forks	51,700	51,700	0	51,700	0	80,900	80,900	0	80,900	0

(1) Computed flows for existing conditions were computed by Modified Puls routing.
(2) Condition 1 refers to encroachments that would raise 1:100 water levels by one-half foot.
(3) Condition 2 refers to encroachments that would limit flow to the main channel or existing dike positions. Flows were not increased to account for the reduction of channel storage.

Table 4 - Impact of various dike encroachments on computed peak flows and levels at Emerson

Year	No encroachment		Condition 1 encroachment (1)				Condition 2 encroachment (2)			
	Discharge (cfs)	Elevation (feet)	Discharge (cfs)	Δ Discharge (3) (cfs)	Elevation (feet)	Δ Elevation (3) (feet)	Discharge (cfs)	Δ Discharge (3) (cfs)	Elevation (feet)	Δ Elevation (3) (feet)
1948	55,300	787.55	56,100	800	787.68	+0.13	64,700	9,400	788.96	+1.41
1950	85,800	790.63	88,100	2,300	790.72	+0.09	114,700	28,900	791.79	+1.16
1965	52,300	786.91	53,600	1,300	787.19	+0.28	71,300	19,000	789.63	+2.72
1966	67,900	789.29	70,200	2,300	789.52	+0.23	84,600	16,700	790.58	+1.29
1969	65,200	788.96	66,700	1,500	789.15	+0.19	81,800	16,600	790.39	+1.43
1975	46,900	785.59	47,700	800	785.80	+0.21	56,100	9,200	787.68	+2.09
1979	84,600	790.53	86,600	2,000	790.63	+0.10	110,700	26,100	791.57	+1.04
Averages				1,600		+0.18		18,000		+1.59

(1) Encroachments that would raise 1:100 water levels by one-half foot.
(2) Encroachments that would limit flow to the main channel or existing dike positions.
(3) Changes are compared to the no encroachment conditions.

C. DISCUSSION

The HEC-5 model was initially calibrated for the Red River of the North using the Straddle-Stagger routing method. However, the model later had to be recalibrated using the Modified Puls method so that the effect of the agricultural diking along the river could be assessed. Unfortunately, the calibrations for the Modified Puls routings are not as accurate, particularly at Emerson. Differences between computed and observed peak flows at Emerson range from 2.4 percent in 1966 to 31.4 percent in 1975. More accurate calibration of the Modified Puls routings would have added credibility to the results listed in Table 4. However, the relative effects of diking given in Table 4 look reasonable and are probably valid. The peak flow in 1979 under full encroachment (Condition 2) would probably have been higher than 110,700 cfs seeing that the calibration underestimated the recorded peak flows by 7,800 cfs (Table 2). However, the increase in peak flow of 26,100 cfs should be reasonably dependable as should the peak stage increase of 1.04 feet.

The preceding discussion is not intended to discredit the modeling effort of the Corps of Engineers. The Red River is long and complex, particularly under flood conditions. Each calibration run was expensive and time consuming. The results are sufficiently accurate for the purposes for which they were intended. Possibly use of the Dynamic Wave Model (DWOPER) referred to in Section II. C. 6. (page 21) would have provided more accurate results in that it is self-calibrating, would correctly handle lateral flow over the dikes, and would compute flows and levels together, thereby eliminating the requirement of using the HEC-2 and HEC-5 models in conjunction with each other. However, the DWOPER model has only recently become available, and experience with it is limited. Therefore, its advantages and disadvantages in comparison with the HEC-2 and HEC-5 models are unknown at this time.

Since the HEC-3 model does not require a calibration phase to simulate a system, the accuracy of the model is difficult to quantify. An indication of the model's accuracy may be obtained by a comparison of recorded and simulated monthly flows for a period in which the simulated demands and system operating rules closely resemble the actual demands and system operating rules. However, since the main purpose of the model is to determine the effect of an existing or proposed project on a historic sequence of flows, the output data will not provide any indication of the accuracy of the model. The usefulness of the model in determining the effect of various projects will depend primarily upon the confidence in which water demands and system operating rules can be defined.

The EAD model of the Red River Basin is reasonably accurate for urban, rural, and transportation damages. It is less accurate for assessing agricultural crop damages.

For urban, rural, and transportation damages the key factor in the model is the elevation versus damage relationship for each reach. This relationship is based on surveys of actual damages which occurred under recent flood conditions, and projections of what damages should be expected under more severe flood conditions. For this model to remain accurate, these curves will have to be reviewed every 2 to 3 years.

The model is less accurate in its determination of agricultural crop damages because it does not consider directly the effect of when the flooding occurs. Flooding will cause no crop damage if the event is early enough in the year that the water recedes and the land dries before the normal date of planting. Also, some crops can sustain limited flooding as long as the water recedes within a day or two. Therefore, an accurate estimate of crop damages requires an analysis of the complete flood hydrograph, rather than only the peak annual flow. Timing is indirectly considered in the EAD model by weighting damages according to actual historic damages. However, structural modifications often alter the timing and duration of flooding, and so historic damages may not provide useful weighting for alternate flood schemes.

V. CONCLUSIONS

The following conclusions refer to the items stated for examination in the Terms of Reference contained in the Appendix.

A. The reduction of floodplain storage resulting from dikes paralleling the river can be expected to increase flows and water levels. Dikes developed to date in North Dakota and Minnesota appear to have increased flows at the international boundary by an approximate average of 2 percent for those years examined by the Corps of Engineers. Diking according to States' criteria of encroachment causing a one-half foot rise for the 1-percent chance flood would have little further effect on flows and would raise the water level above the no encroachment level by approximately two-tenths of a foot at the international boundary. However, if dikes were constructed along both riverbanks from Grand Forks to Emerson, peak flows would be increased by 20 to 25 percent and peak water levels would be raised by approximately 1 1/2 feet at the international boundary.

The modification of existing dikes and the construction of ring dikes would have no significant impact on the peak flows or water levels at the international boundary.

B. The existing reservoirs in the headwaters of the Red River of the North have a negligible effect on flood peak and timing because of their limited storages. There are presently no structures being planned in either North Dakota or Minnesota that could significantly change peak flows or water levels at the international boundary.

C. The four computer models of the Red River of the North cannot be used to assess the impact of agricultural drainage on the flow regime at the international boundary. The USGS is presently conducting a study of the historic streamflow record to identify changes in the hydrologic response of the Red River that may have resulted from land use changes in the basin. The report will be submitted to the Souris-Red-Rainy Regional Committee of the Upper Mississippi River Basin Commission in late 1981.

D. The four models could be expanded for the Red River from Emerson to Winnipeg for a total cost of $70,000 to $80,000. This cost would include data acquisition and model calibration costs. Extension of the models into Canada is not necessary at this time because of the small impact that existing diking in the United States would have on peak flows and water levels at the international boundary. In addition, backwater and routing models have already been developed for the Red River between the international boundary and Winnipeg. Further development of the routing model may be undertaken under the flood forecasting subagreement of the Canada-Manitoba Flood Damage Reduction Program.

INTERNATIONAL SOURIS-RED RIVERS ENGINEERING BOARD

REPORT OF RED RIVER MODELING TASK FORCE

APPENDIX

SEPTEMBER 1981

80 10 08

INTERNATIONAL SOURIS-RED RIVERS ENGINEERING BOARD

TERMS OF REFERENCE

RED RIVER MODELLING TASK FORCE

OBJECTIVES

The objectives of the Red River Modelling Task Force will be to review the four computer models being considered by the United States Army Corps of Engineers for modelling the Red River basin in the United States and to prepare a report on the capabilities of these models of providing data and technical information related to concerns under consideration by the International Souris-Red Rivers Engineering Board. The low flow model (HEC-3), water surface profile model (HEC-2), the high flow model (HEC-5) and expected annual damages model (EAD) will be examined to determine if they can provide suitable technical information as follows:

1. The impact of existing and proposed river or ring dikes on flow conditions at the international boundary.

2. The impact of existing and proposed works such as reservoir and dike modifications on flow conditions at the international boundary.

3. The impact of agricultural drainage on flow regime at the international boundary.

4. The possibility of an expansion model being developed for the entire Red River basin.

MEMBERSHIP

Membership of the Task Force will consist of no more than six members. Members will be nominated by the International Souris-Red Rivers Engineering Board with due regard for the interests of agencies in each country.

The chairman of each section of the Board will appoint one Task Force member to be a co-chairman of the Task Force.

Task Force members may appoint alternates to represent them at meetings of the Task Force if they are unable to attend. Any member appointing an alternate will promptly advise the chairmen of the Task Force.

MEETINGS

The Task Force will meet as required, including joint meetings when requested by the Board.

REPORTS

The Task Force will prepare two reports for the Board:

a. An Initial Report describing the models and their application as outlined in the objectives shall be provided to the Board by March 31, 1981.

b. A Final Report which shall include a description of the Task Force activities, an assessment of the programs set out in the objectives and recommendations respecting their application to matters of concern to the Board shall be provided by September 1, 1981. The Final Report shall also include any other items that the Task Force considers to be of importance to the modelling of the Red River basin.

The Task Force shall provide minutes of their meetings to the Board.

The Board may request progress reports from the Task Force.

PLAN OF STUDY

The Plan of Study will encompass four major tasks. Fulfillment of Tasks 1, 2, and 3 will likely be achieved during the study while the fulfillment of Task 4 will depend on the progress of the forecasting study under the Canada-Manitoba Flood Damage Reduction Program.

The Task Force will utilize the resources of the appropriate federal, state, and provincial agencies in carrying out the studies associated with the following tasks:

1. Evaluate and report on the capabilities of the four models (HEC-3, HEC-2, HEC-5, and EAD) of the United States Army Corps of Engineers.

2. Describe how each of the models could be utilized to determine the influence of dikes, dredging, storage reservoirs, agricultural drainage, etc., at the international boundary. Rate the ability of each model to produce the necessary information at the boundary and provide comparisons of cost of operation of the models.

3. Describe the technical feasibility of extending the models to the entire Red River basin upstream of Winnipeg. Make recommendations on the most feasible alternatives and make an estimate of the cost.

4. Under the Canada-Manitoba Flood Damage Reduction Program (FDRP) several flood forecasting procedures will be investigated. The chairmen of the Task Force shall maintain a continual liaison with the FDRP Task Force Chairmen and shall advise the Board on the progress of those investigations.

5. Describe the flood plain information which must be collected and its magnitude to make the model predictions valid within reason.

END

FILMED

11-84

DTIC